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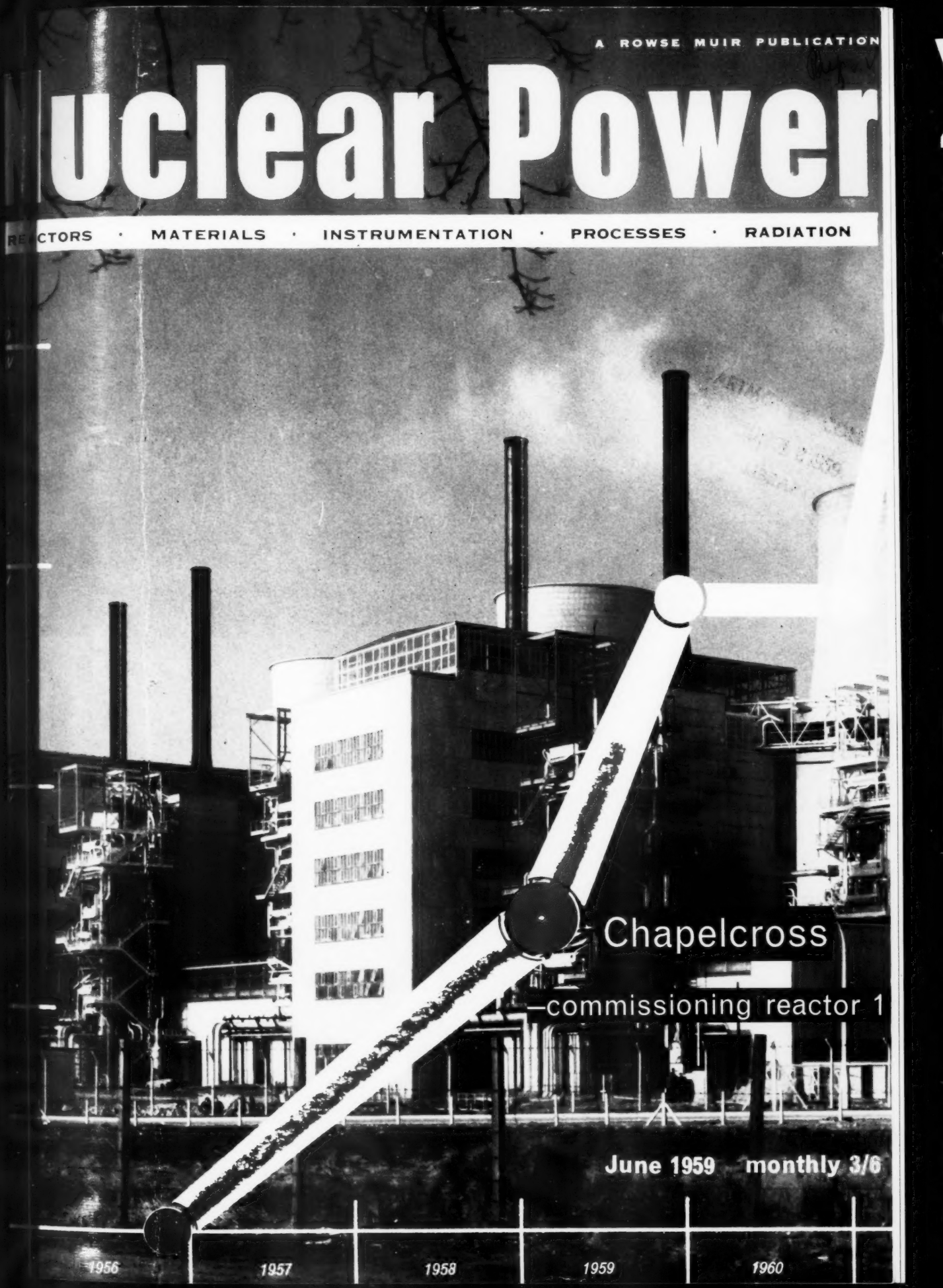
Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · RADIATION



Chapelcross

—commissioning reactor 1

June 1959 monthly 3/6

1956 1957 1958 1959 1960

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Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · RADIATION

VOL 4 NO 38 JUNE 1959

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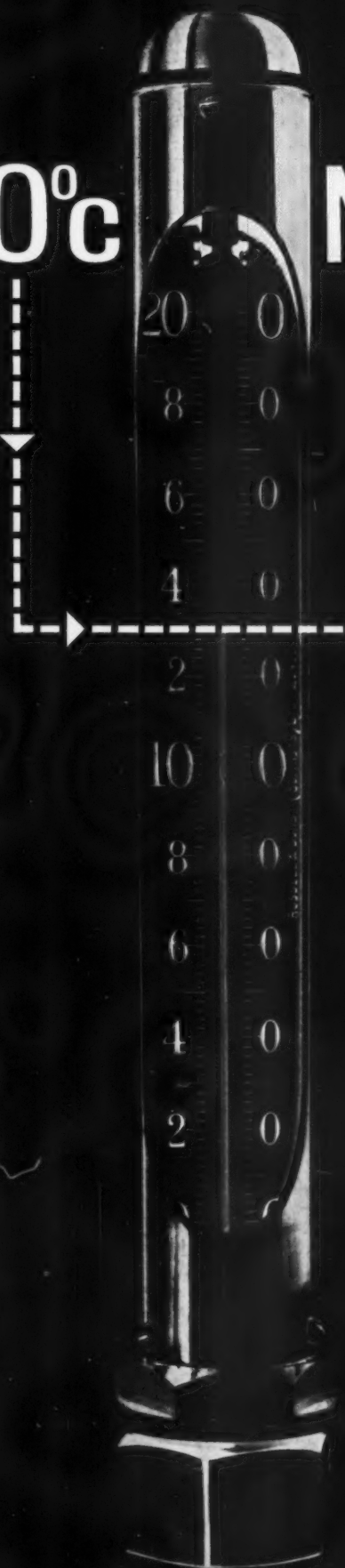


AT THIS DANGER MARK

for Shell Alvania

For years now Shell Alvania greases have been a byword for stability in roller bearings. What is the secret? Lithium 12 hydroxy stearate, one of Shell's prized patents.

But stability is not enough. As new industrial techniques have been developed and new machines evolved, new problems have emerged with them and old problems have been intensified. Shell research teams at Thornton have made it their business to find the answers.

First problem was the *length of life of the grease charge* at the higher running temperatures of some modern machines. Could this life be lengthened? Shell scientists, through new Shell Alvania, have given an emphatic answer – at 130°C., the danger mark where most greases fail quickly through dynamic oxidation, Shell Alvania will live three times as long.

The second associated problem was the oxidation promoted by yellow metal cages. Could this be reduced? The answer, in Shell Alvania, is the virtual suppression of the effects of yellow metal.

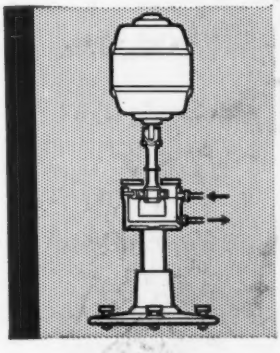
Problem three was corrosion caused by moisture. Could this be prevented? The answer was given in the Thornton Wet Bearing Rig Test*, where new Shell Alvania won an anti-corrosion rating of 10 out of 10.

New Shell Alvania greases were put on the market in March, 1957, and already, as proof of their success, tens of thousands of new electric motors leave British makers' works each week with Shell Alvania greases in their bearings.

What is the moral of the Shell Alvania story? That Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right grease for the job. If you and your organisation have any major lubrication problems, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

*In the Thornton Wet Bearing Rig Test water was fed through a 20 mm. bore bearing with a special demountable plastic cage (to simplify inspection) charged with the grease under examination to a weighed quantity rotating at 3,000 r.p.m. The rate of supply of water was one gallon per minute, the water running to waste. After 5 hours' operation the bearing was removed and stored horizontally half immersed in water for three days. Anti-corrosion merit ratings were given at the end of the test. High-quality greases without special protectives showed an average rating of 3 out of 10, while new Shell Alvania rated 10 out of 10.



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ALVANIA GREASES

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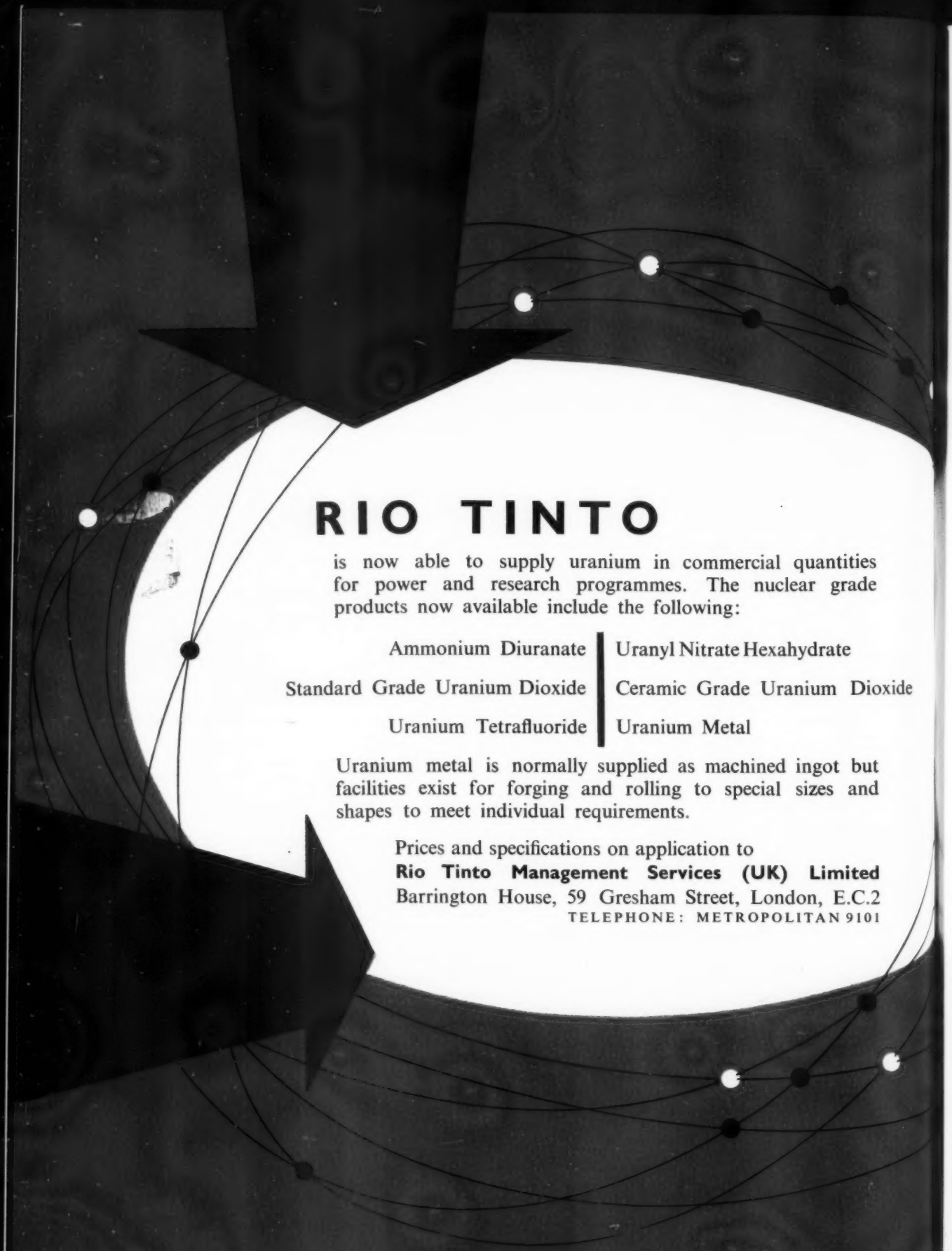

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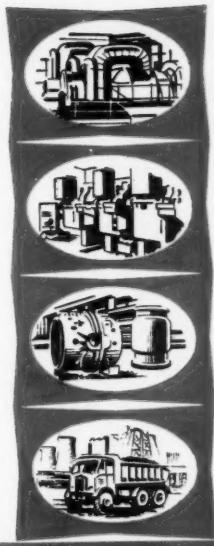

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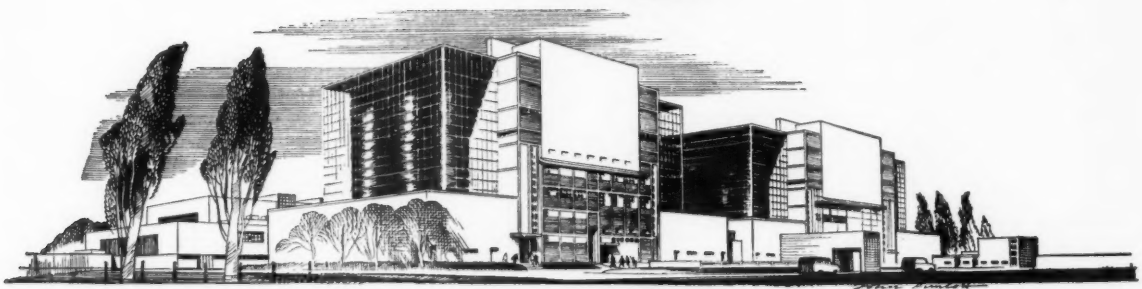
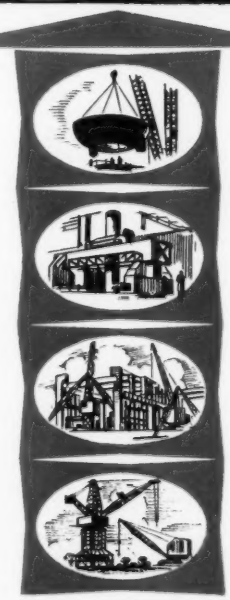


Bradwell, Essex, has leapt into fame as the site of the first commercial nuclear power station in the world to be built by N.P.P.C. Eight names make The Nuclear Power Plant Company Limited. N.P.P.C. thus combines the resources of eight specialist companies whose individual skills are co-ordinated to form a unified team capable of undertaking the construction of complete nuclear power stations throughout the world.

Bradwell nuclear power station will have a guaranteed output of 300 Megawatts. It is being built by The Nuclear Power Plant Co. Ltd. for the Central Electricity Authority.



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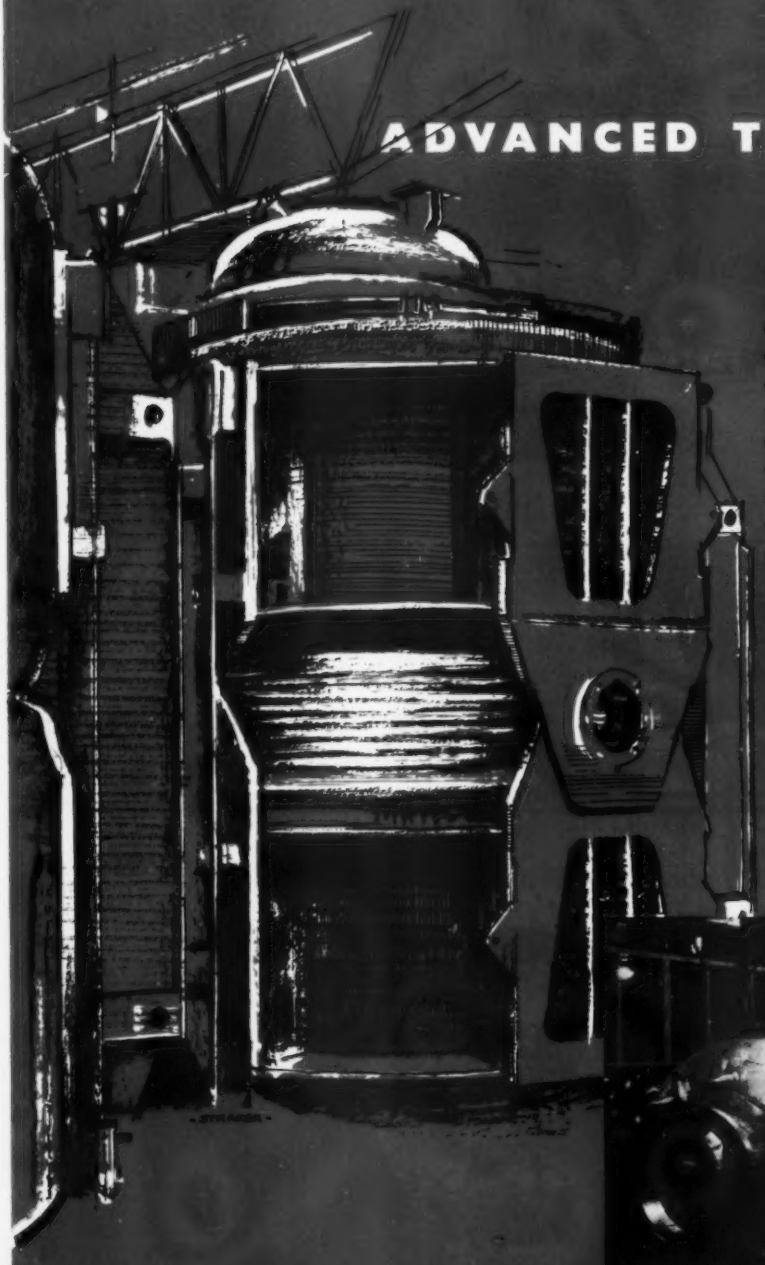

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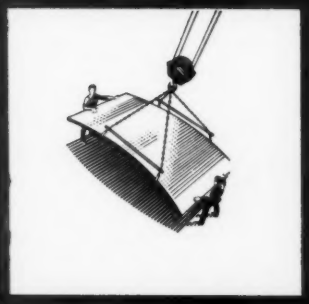

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DESIGNED AND BUILT

THE REACTOR PRESSURE VESSELS

AT CALDER HALL

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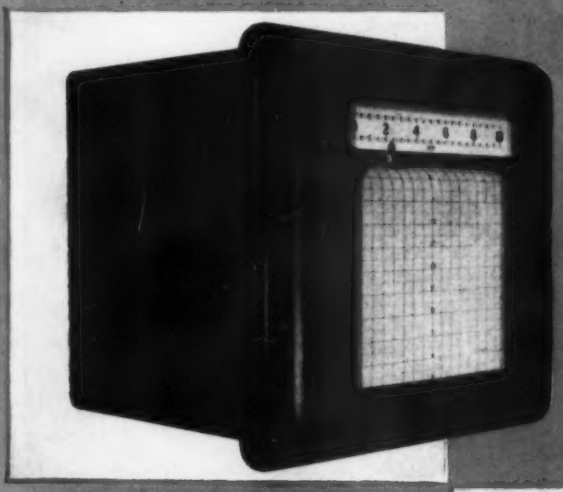

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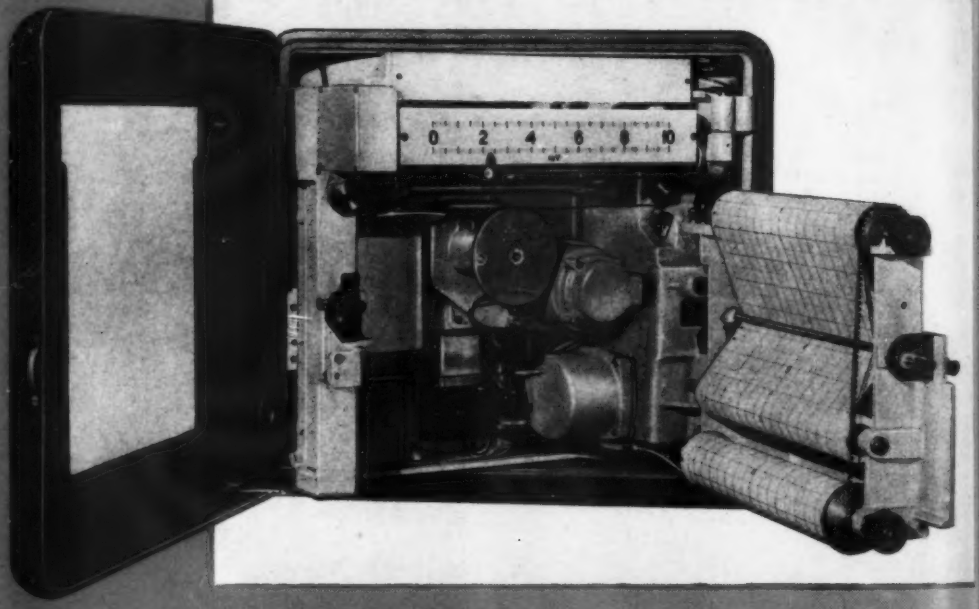

Mark 3 Multelec *recorder, showing the chart frame swung away to allow ready access to the main-frame components; plug-in amplifier, etc. is easily reached by swinging forward the main frame*

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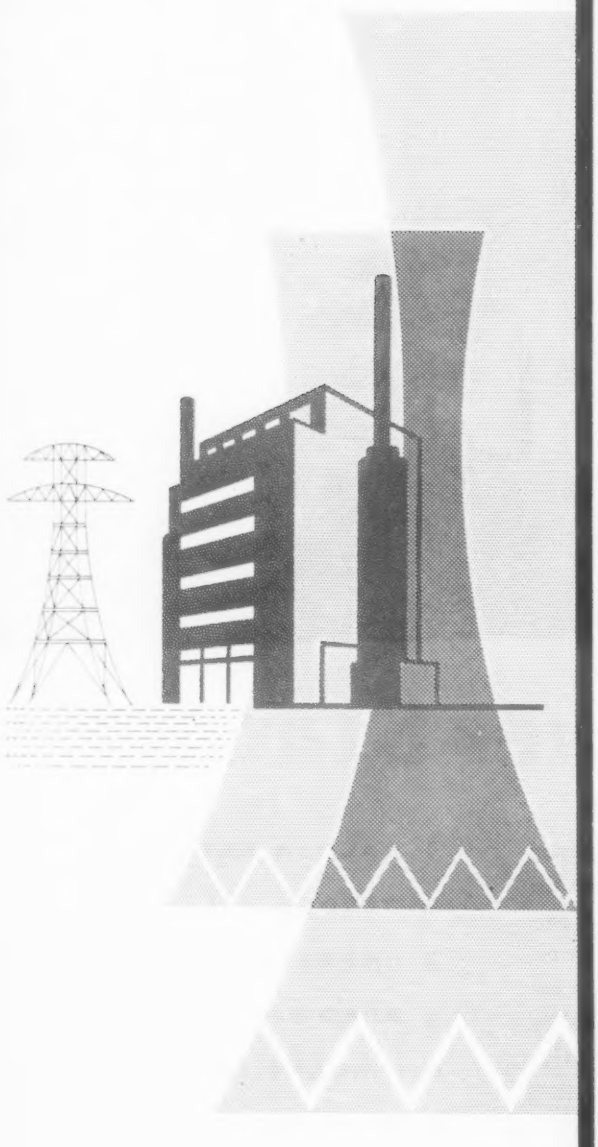

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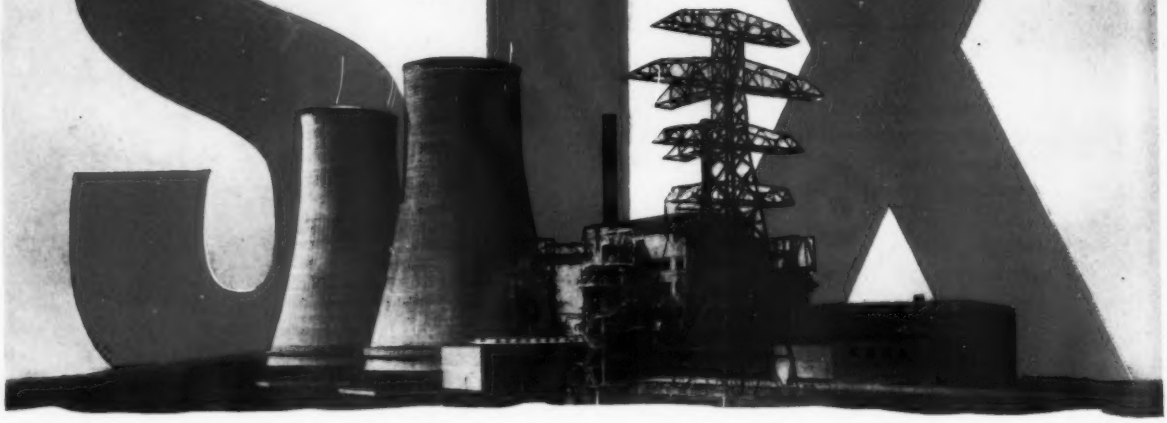

Atomic Power Stations

Permutit have now obtained contracts for supplying plant to six Atomic Power Stations. This follows the successful installation of "Deminrolit" plant for providing feed water for heat exchangers at the Atomic Power Station at Calder Hall. "Deminrolit" is but one of a range of plants designed and manufactured by Permutit to treat water and non-aqueous liquors in factories and research establishments associated with nuclear power development.

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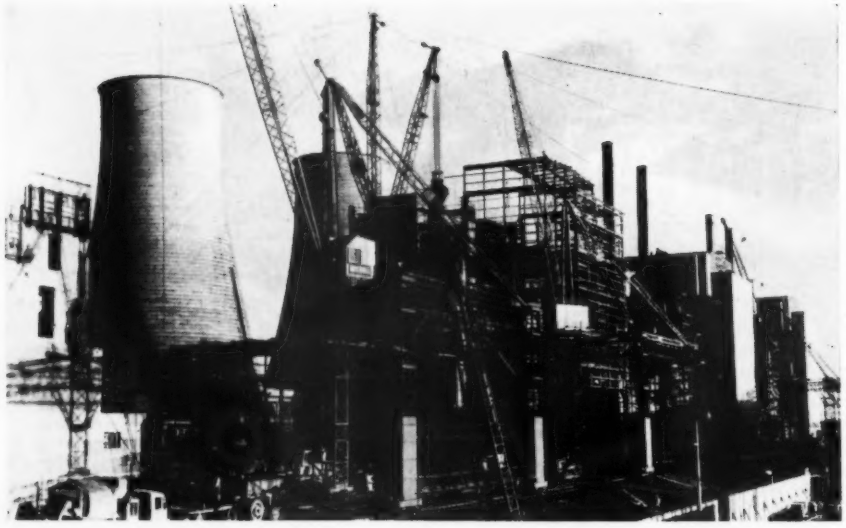

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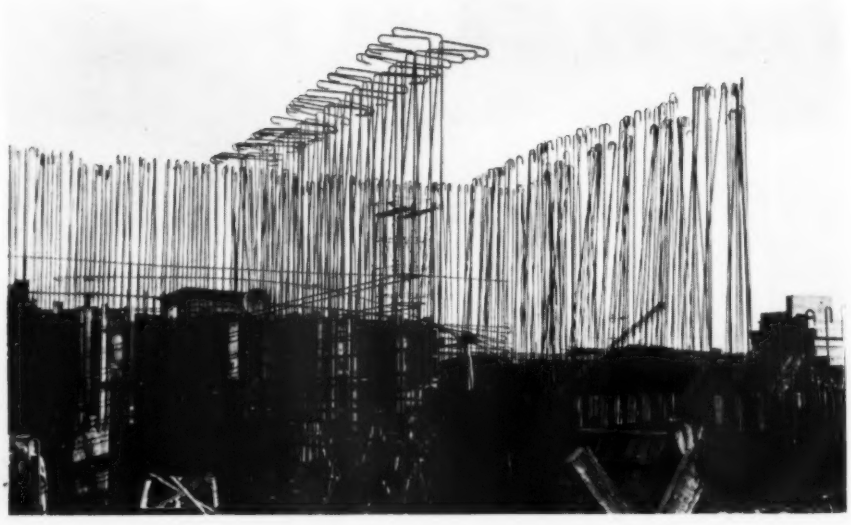

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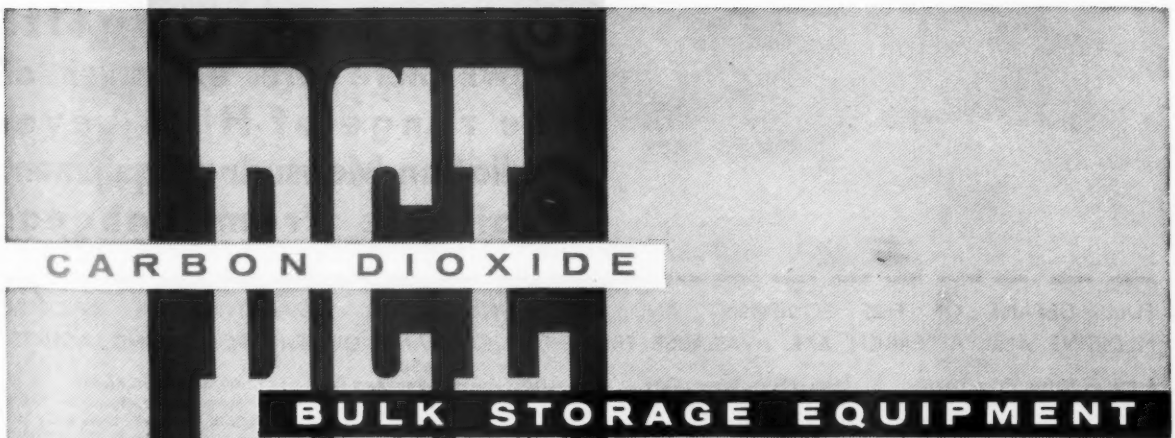

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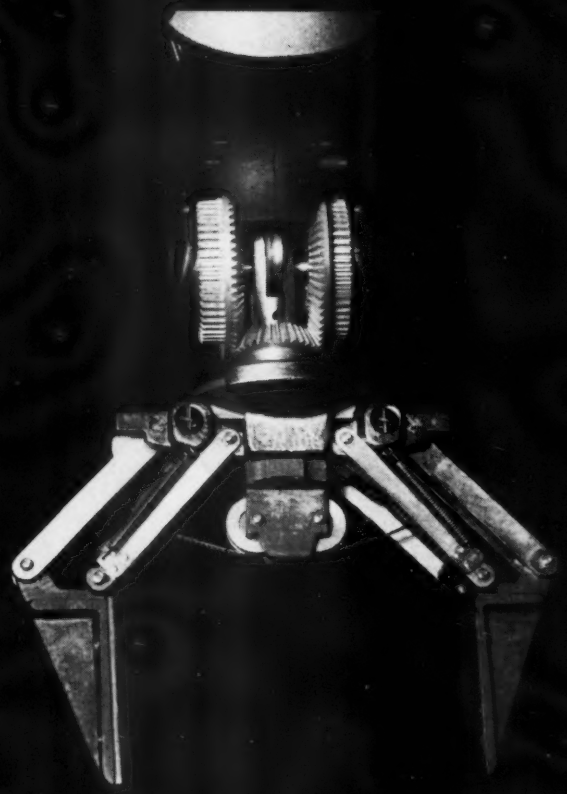

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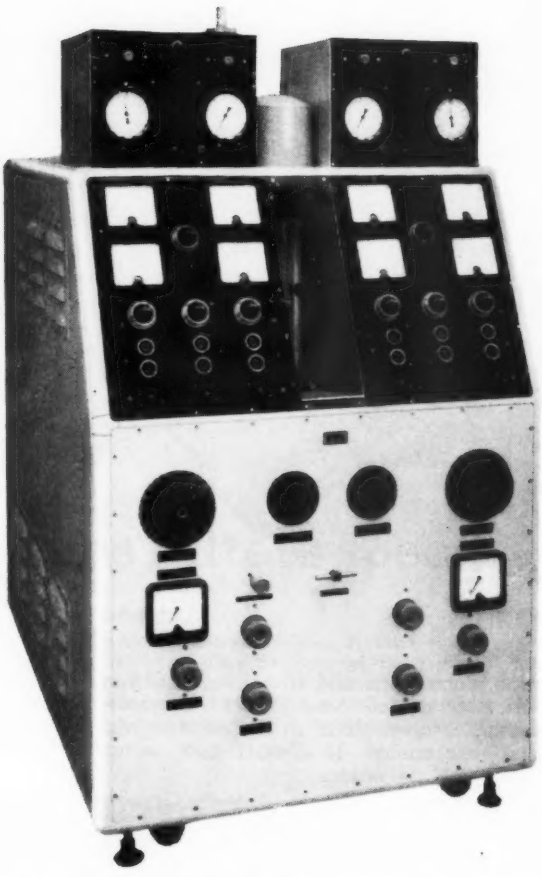

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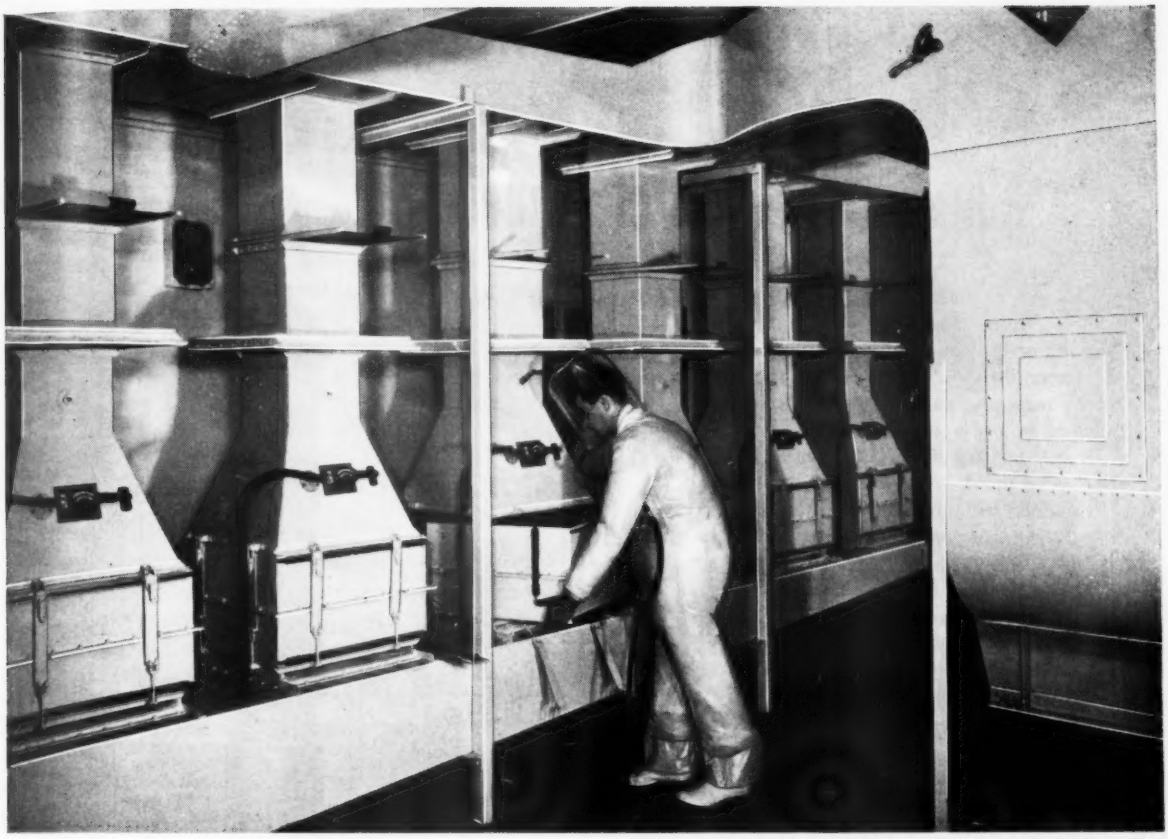

One of two banks of Vokes 'Absolute' filters in the G.E.C. beryllium laboratory, showing operator in a pressure suit changing a filter.

Vokes Filters specified for work on Beryllium

New Beryllium Laboratory

At the G.E.C. Atomic Energy Division at Erith a new laboratory has been specially designed for work on beryllium. Vokes were called in to assist in the planning of a ventilating system designed to maintain a very high standard of safety and to conform with the recommendations of the U.K.A.E.A.

A Vokes filter can be seen on the left of the lathe enclosed in the PERSPEX working box.

Vokes 'Absolute' Filters

The laboratory areas are fully air-conditioned by means of a central inlet air duct and there is a range of extract ducting running along the laboratory walls.

The extraction system consists basically of a fan drawing air at the rate of 8,000 cub. ft. per min. from the laboratory through 12 Vokes 'Absolute' filters arranged in two banks of six, coupled in parallel to the extract fan. Each of these filters is individually mounted in a cell on the manifold to minimise hazards during filter changing.

The Vokes 'Absolute' filter has a guaranteed efficiency of 99.95% in the 0.1 to 0.5 micron range. For particles greater than 1 micron the efficiency is virtually 100%. The plant has been arranged so that the filters can be changed with the ventilation plant running.

Working Boxes fitted with Vokes Filters

Operations involving the formation of beryllium dust, such as machining, abrasion and welding, are confined to a laboratory where the highest ventilation rate is available and is carried on in ventilated working boxes, which also incorporate Vokes filters.

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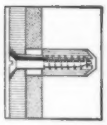

RAWLPLUGS for neat firm fixings in brick, stone, etc. Rotproofed and waterproofed for use in all climatic conditions. All screw sizes up to ⅜" diameter coach screws.

Rawlplug WHITE BRONZE PLUGS for fixings subject to very high temperatures, such as the outer brick coverings of furnaces. Also for underwater fixtures.

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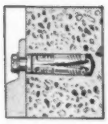

RAWLBOLTS for bolting down machines—a rock-firm *dry* fixing that grips by expansion. No cold chiselling, no waiting for cement to harden. Sizes up to 1" bolt diameter.

Rawlplug BOLT ANCHORS for bolting down in extremely wet or corrosive situations. Caulking completely seals the anchorage. Also for anchoring Diesel Generators, Power Hammers, etc.

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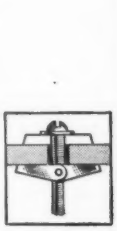

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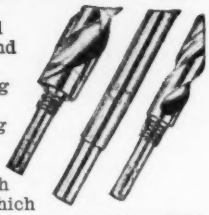
With its ultra-tough, almost diamond-hard Durium tip, and its patented rapid-helix flute to force out spoil and prevent clogging, Durium drills brick, tile, cement, slate, marble, etc. with a speed of penetration that is truly amazing.
It is this same toughness of the Durium tip, and the stronger backing given it by the specially designed flute, that gives a Durium Drill its astonishing ability to stand up to the abrasive action of masonry which so quickly ruins ordinary drills.
Only a Durium Drill has such sharp, silent, easy cutting accuracy, such amazing drilling speed, such sheer durability!

FULL RANGE—DRILLING LENGTHS UP TO 16" TOO!



Durium Drills are made for all sizes of Rawlplugs from No. 6 to No. 30 (i.e. drill cutting diameters from 5/32" up to 1") and also for Rawlbolts sizes C, D, E & G.
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21 different types of fixing devices for speed and strength

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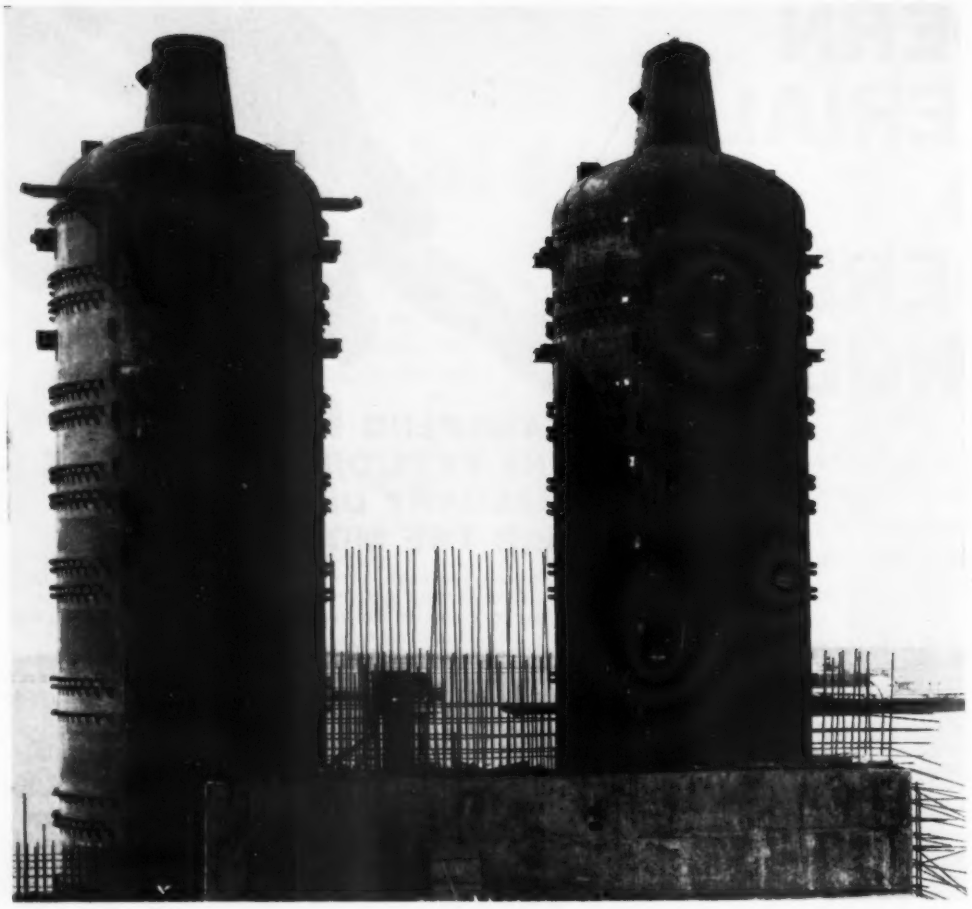

Every inch is seen to be perfect

The heat exchangers for the Bradwell station are so large they had to be towed to the site by sea.

There are 12 of these exchangers, designed and manufactured by Head Wrightson & Co. Ltd. Each weighs 200 tons and includes low-pressure and high-pressure systems.

The shells of the exchangers consist of four circumferential plates in 12 tiers. The plates are first tack-welded into place and the internal and external longitudinal welds are then made with automatic submerged-arc sets to Lloyds Class 1 specifications. Every inch of every weld is then X-rayed.

The dished ends, consisting of eight segments pressed to shape, are hand-welded, double-U preparations being used. The reinforcing ring outlets and flanges are then welded into position and X-rayed.

The importance of the radiographic inspection on a project of this magnitude cannot be over-emphasised. Not only must every inch of every weld be perfect—it must be *seen* to be perfect. That is why Kodak 'Industrex' X-ray Films were used exclusively for the heat exchangers of Bradwell Nuclear Power Station.

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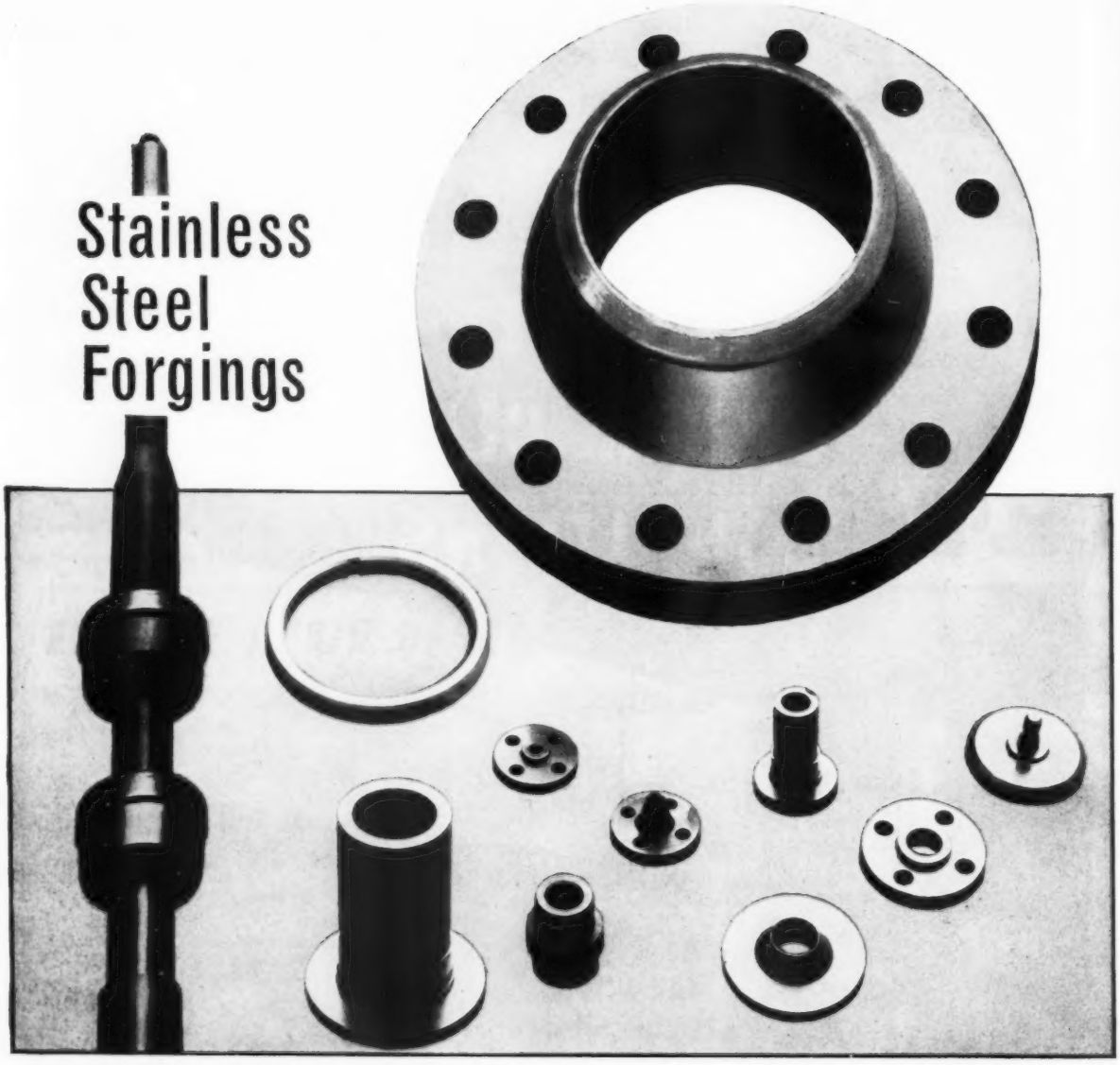

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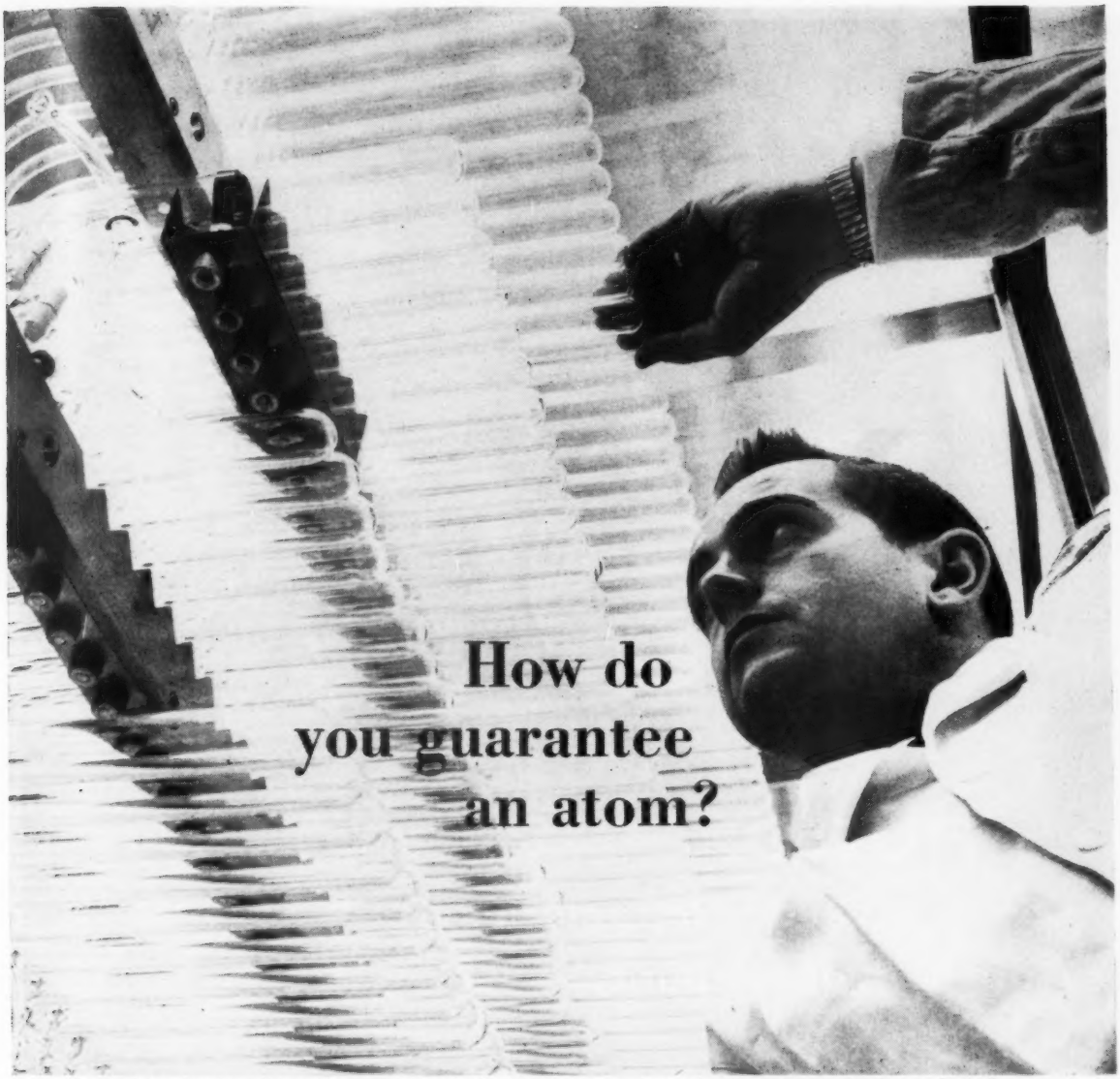

Atomics International technician with countercurrent distribution apparatus used to study moderator-coolant for Organic Power Reactor.

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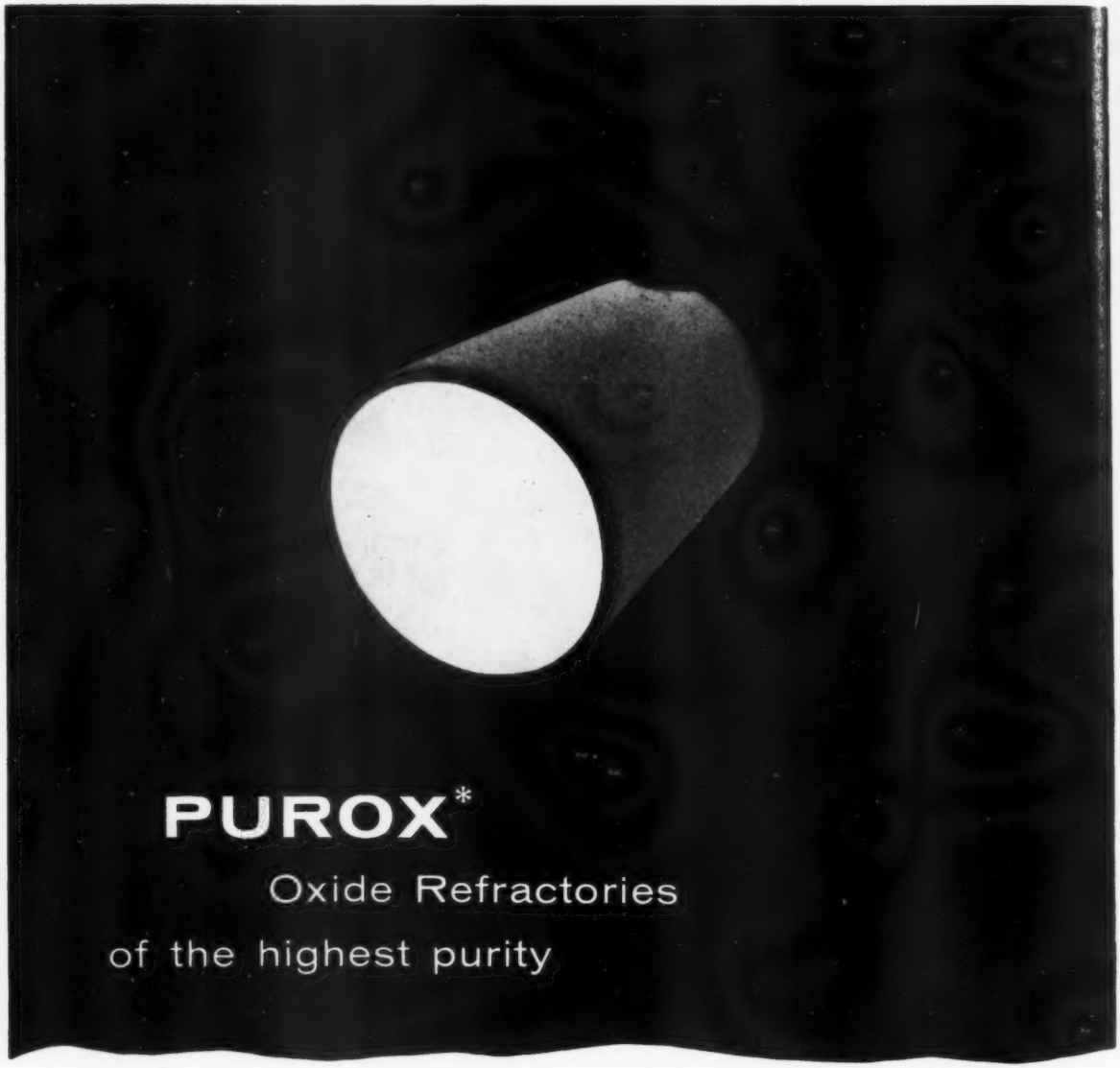

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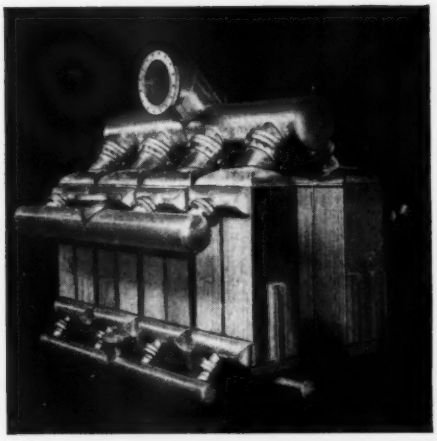

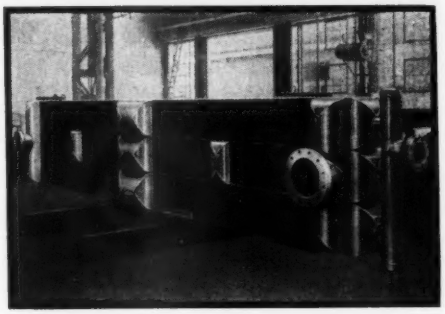

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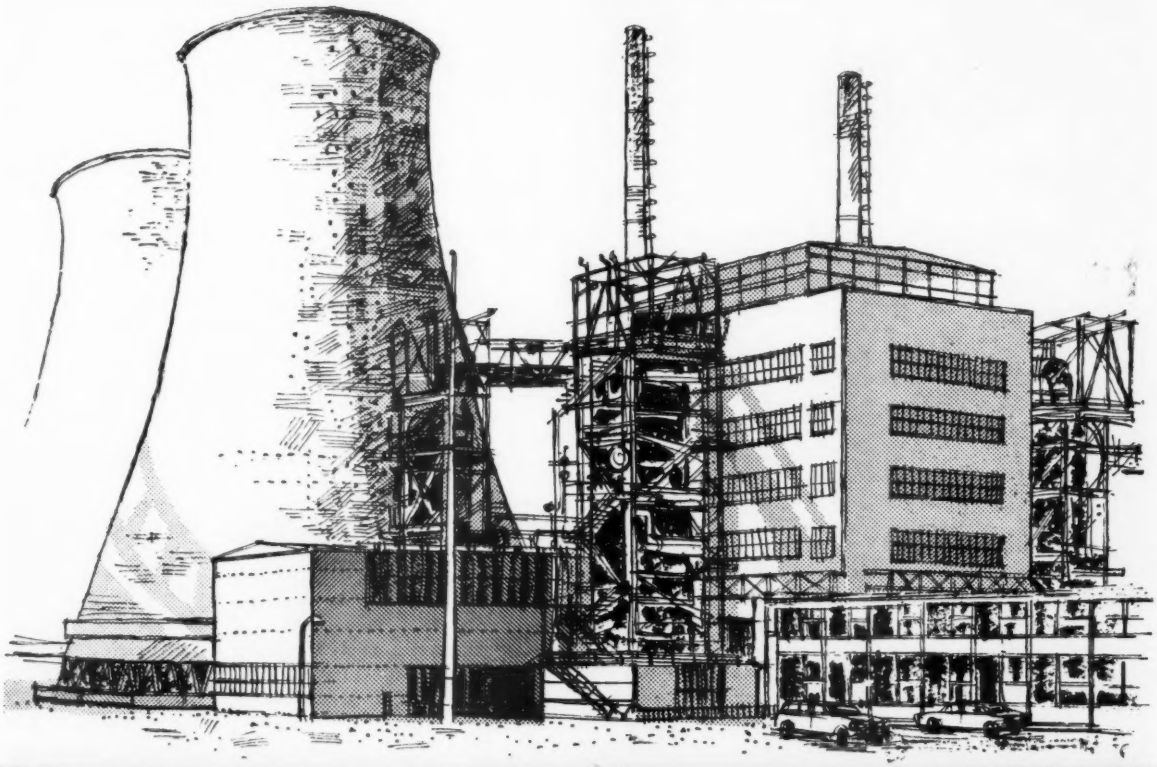

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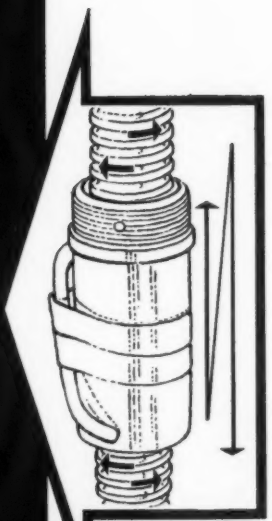

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constant tension supports

FOR LOADS UP TO 8 TONS
PIPE MOVEMENTS UP TO 18"

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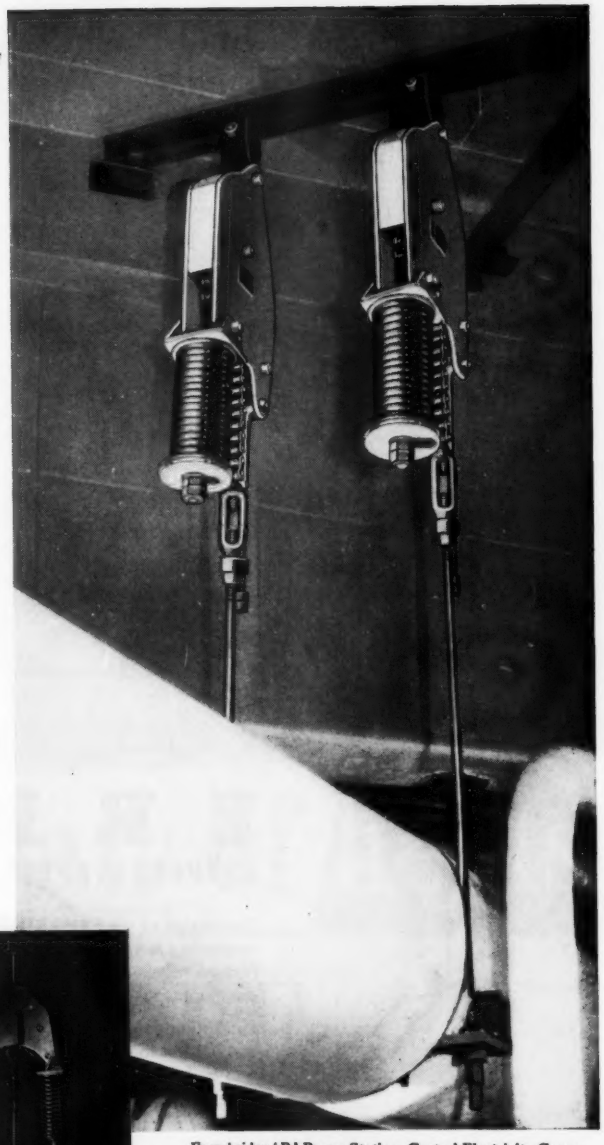

Ferrybridge 'B' Power Station, Central Electricity Generating Board, Yorkshire Division. H.P. Steam pipes supplied and installed by Stewarts and Lloyds Ltd.

Leibtried Red Top Pipe Supports for loads from 100 to 5,000 lbs. and total travel of 3".

Conventional type "Con-Ten" Supports for loads of up to 2 tons with a total vertical movement up to 12".

Duplex "Con-Ten" Supports for loads of up to 8 tons with a total vertical movement up to 12". This type is acknowledged as one which produces minimum friction and kinematic variation. It has been specially designed for any applications where exceptional accuracy is demanded,

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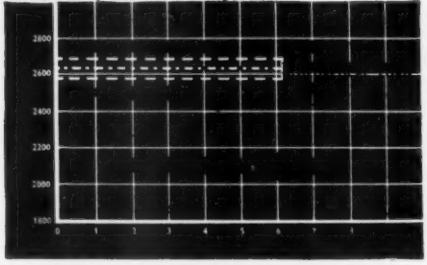

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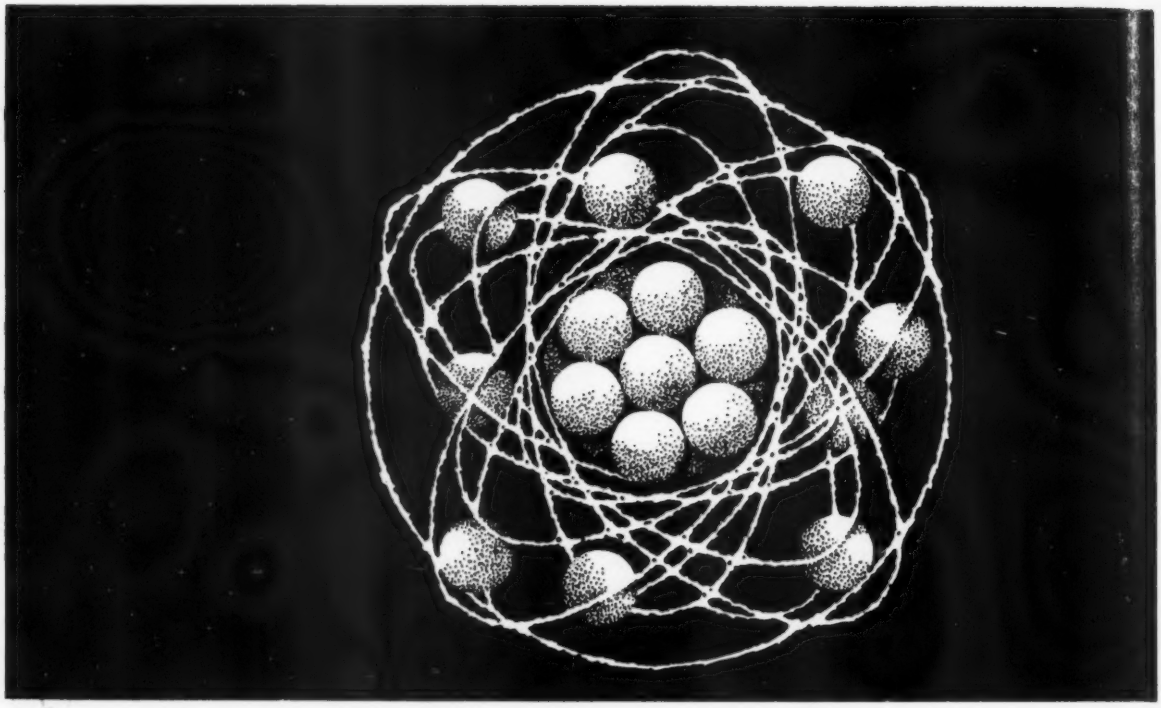

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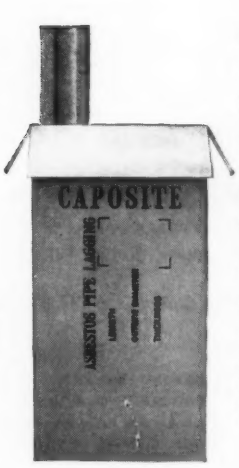

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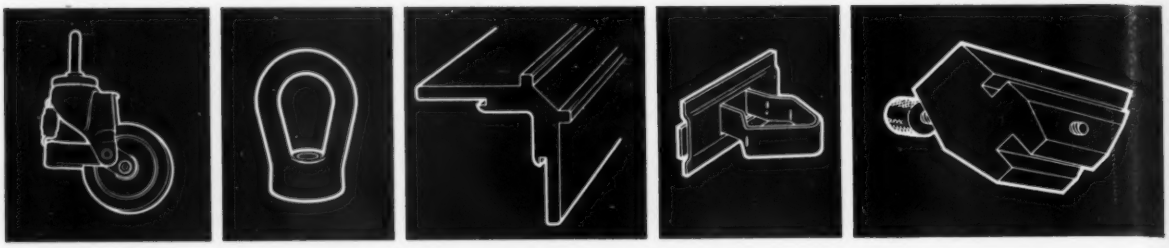
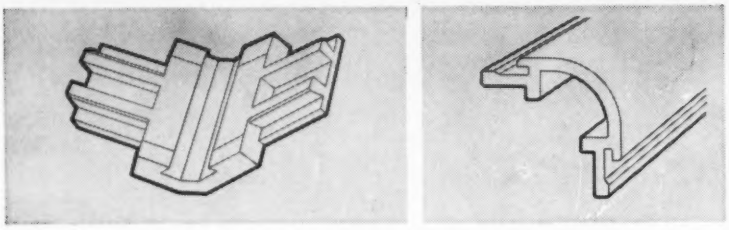
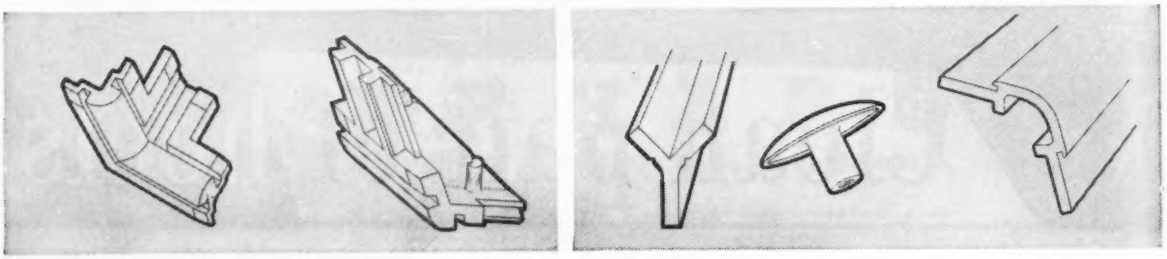
62 big Imlok developments

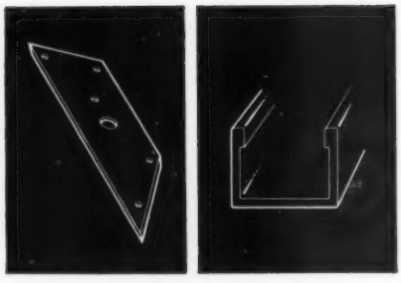
TO SAVE YOU MONEY ON CASE CONSTRUCTION!





IMLOK—the unique cabinet construction system—now offers designers and engineers even more possibilities than before. Fifty-six new parts have been added to the already wide range of precision-made corner connectors, extrusions and accessories, and you can now buy Imlok in six different stages of manufacture. It means more versatility . . . more scope in case and cabinet design. The Imlok system is ideal for both prototype and production work





56 new parts

The addition of new connectors and extrusions means you can now have external or internal angles from 22½° to 90°. The new range also includes strengthening extrusions for extra heavy-duty structures, fashion trims, door pulls, castors, and many more. Full list on request

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IMLOK

New 36-Page Imlok Manual

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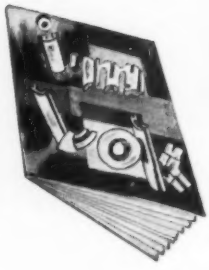

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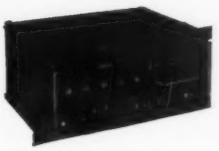

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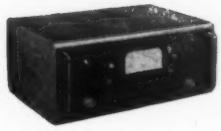

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- ★ **MEASURES contamination of any resulting effluent.**

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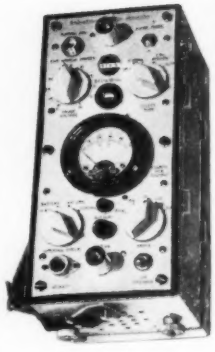

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3. Following the progress of radio-active tracer elements in medical, geological, agricultural and industrial processes.
4. Tracing the whereabouts of radio-active areas and making accurate assays of samples in geological surveys.
5. Tracing lost samples of radio-active materials both in buildings and out.

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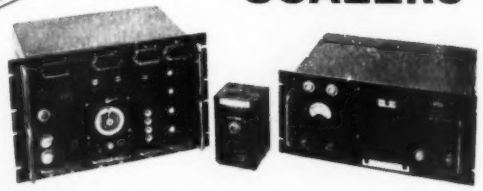
SCALERS



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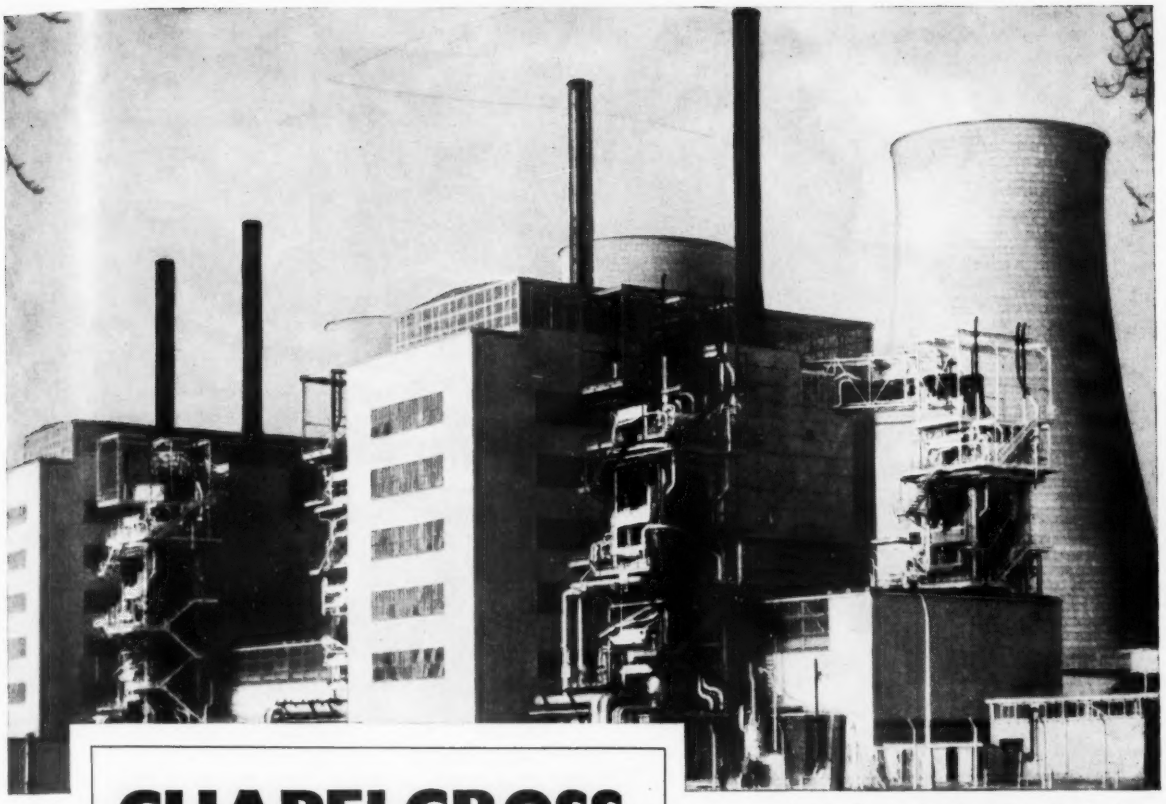
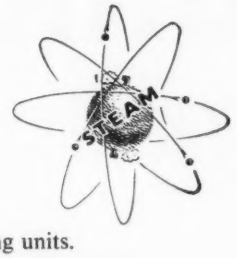
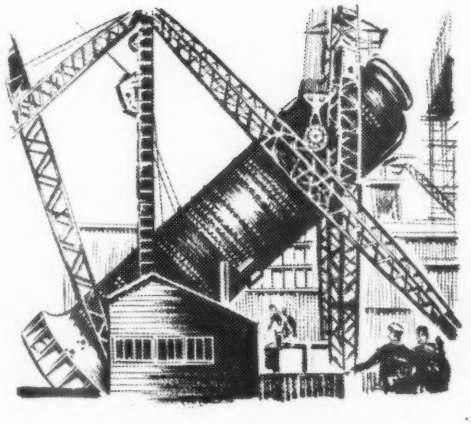


CHAPELCROSS

View at Chapelcross power station showing some of the 16 Babcock steam-raising units.

BABCOCK & WILCOX LIMITED have been responsible for the design, manufacture and installation of all the steam-raising plant for the new Chapelcross atomic power station. This plant, comprising **sixteen 80-feet high steam-raising units** (heat-exchangers) of the Babcock dual-pressure type, is essentially a duplicate of that at Calder Hall, which has been in successful service since 1956, for which also Babcock & Wilcox supplied all the sixteen steam-raising units.



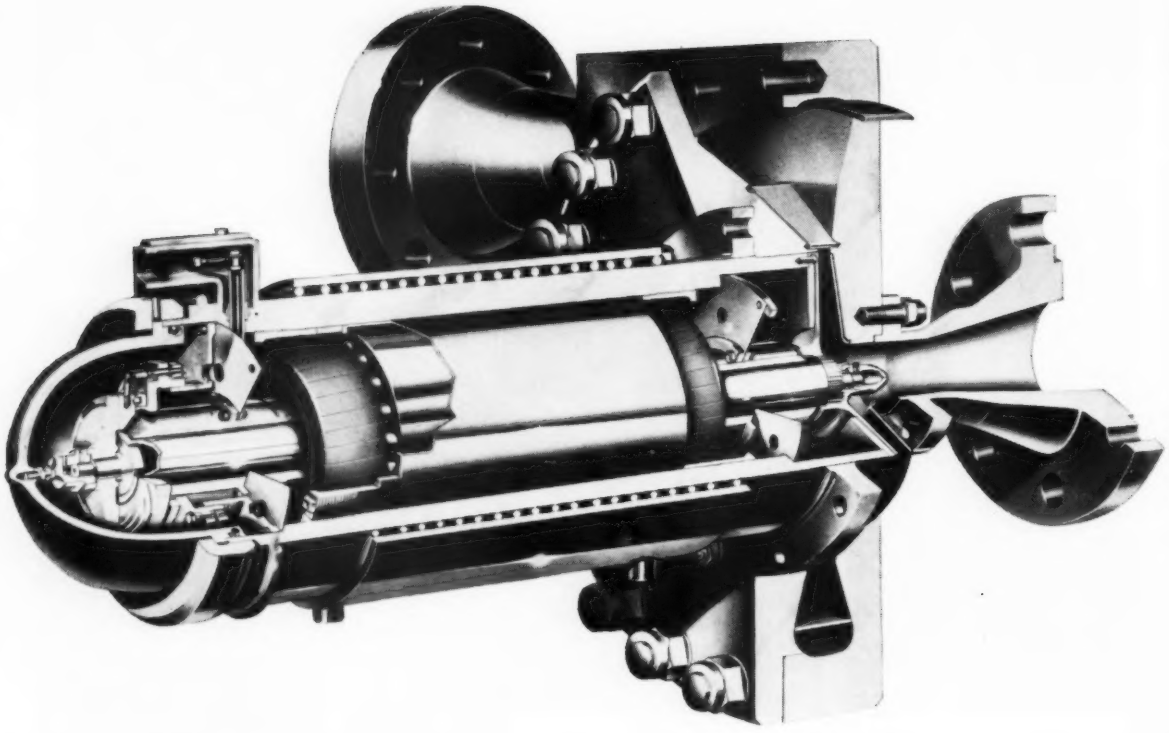


It is indeed a prototype of the steam-raising equipment for all the much larger atomic power stations now under construction in Great Britain, a programme in which Babcock & Wilcox are playing a major part. Babcock equipment at Chapelcross includes also a number of Goliath and other cranes, travelling platforms, etc. for spent-fuel handling and other services.

BABCOCK

ATOMIC POWER PLANT

BABCOCK & WILCOX LIMITED, BABCOCK HOUSE, 209 EUSTON ROAD, LONDON, N.W.1.



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ILLUSTRATED
(right) Hood Tube Assembly undergoing alignment and accuracy testing in the Butterfield workshops (far right) Component parts for Irradiation Tubes and Liners (below) Irradiation Hood Tubes and Liners during construction at the Power Station

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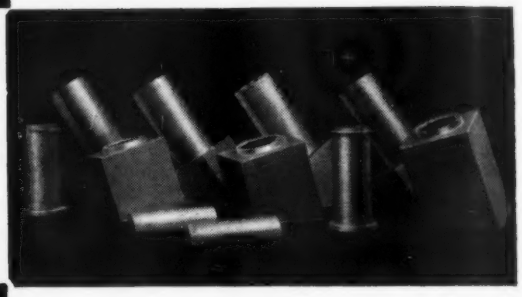

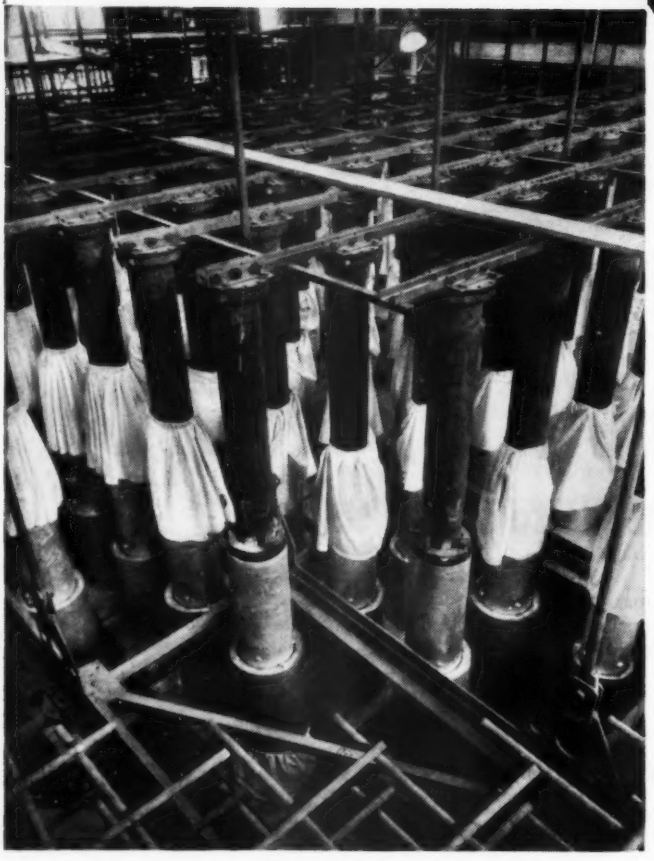

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PNEUTOMATION

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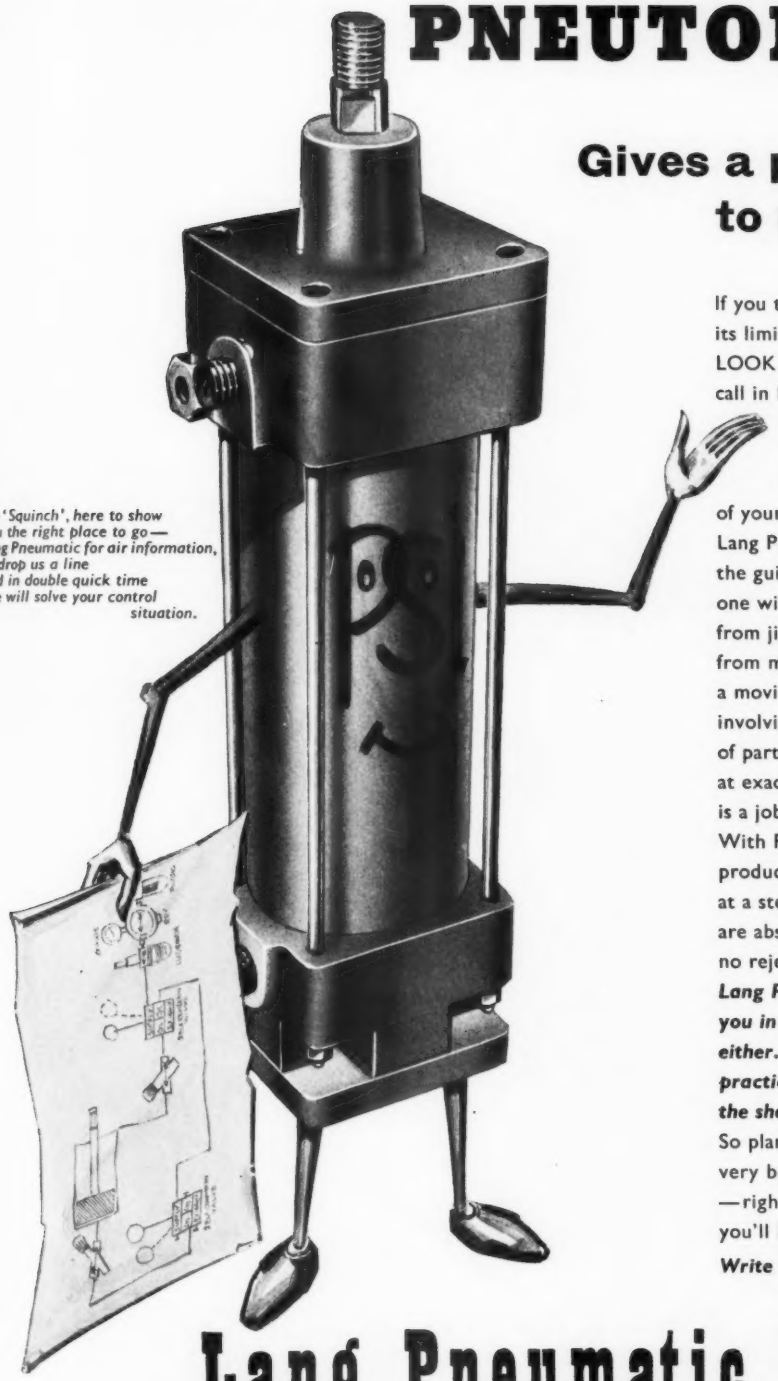

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You the right place to go—
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So drop us a line
And in double quick time
We will solve your control situation.

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LOOK AGAIN! Better still, call in Lang Pneumatic to do the detective work. Chances are, 'Pneutomation' could squeeze that extra effort out of so many of your processes.

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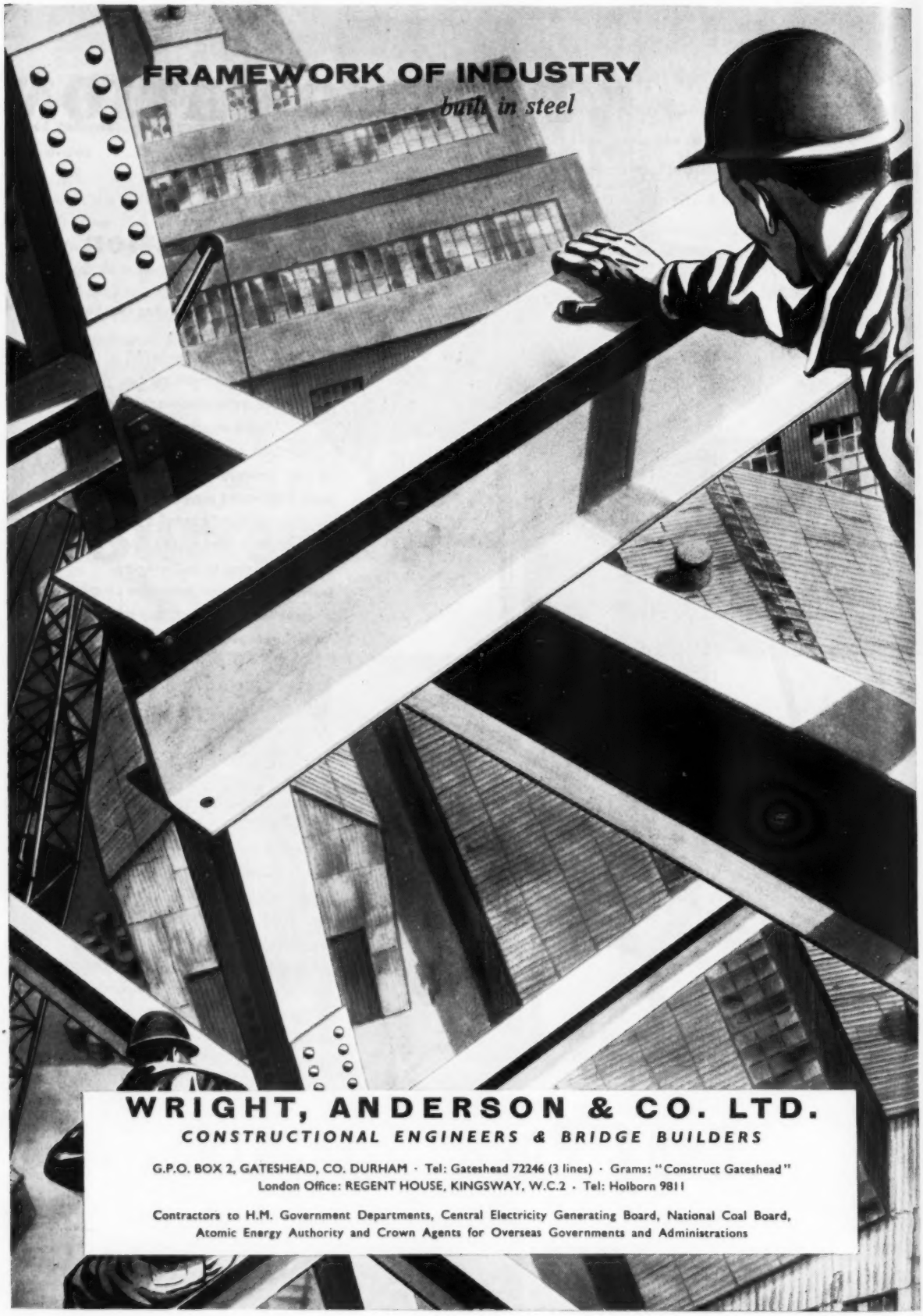
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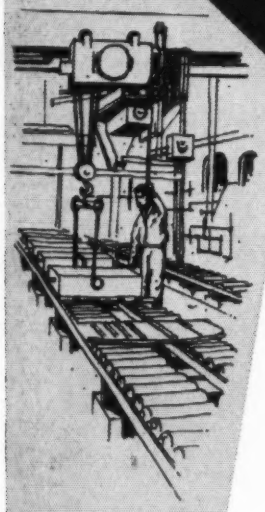

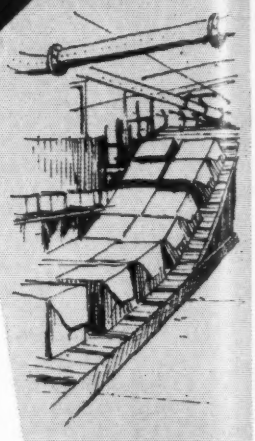

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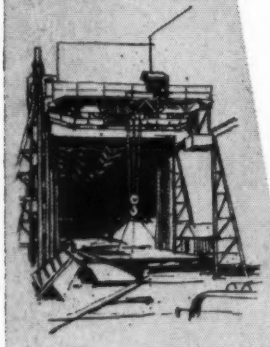

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The Foundry Division has long experience in the foundry industry. Many examples of Paterson Hughes pouring runways, conveyor systems, complete sand handling plants, cupola charging plants, casting cooling conveyors, are at work throughout the industry today.

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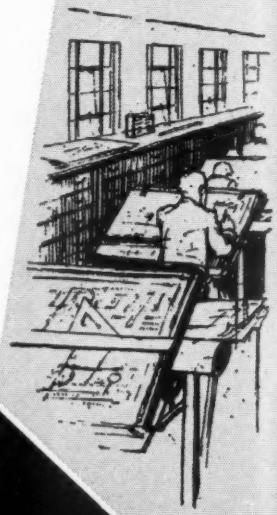

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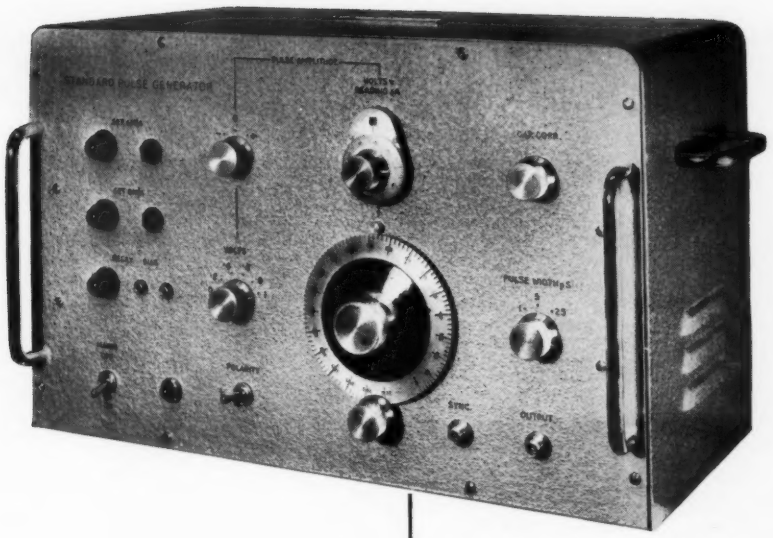

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Standard Pulse Generator

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Full technical specification from

SUNVIC CONTROLS LTD

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Main: 0-40V with linear accuracy ± 80mV

Incremental: 0-1.2V with linear accuracy ± 2mV.

STABILITY.

Over 8-hour period: better than ± 0.05% allowing mains variation of ± 5%

PULSE CHARACTERISTICS.

	PULSE 1	WIDTH 5	IN μ SEC. 25
Rise Time 10-90%	0.4	2.0	25
Width at 0.5 peak	1.75	8.75	43.7
Decay time 100-10%	3.0	15.0	75

SUNVIC

An A.E.I Company

Control and research equipment for science and industry

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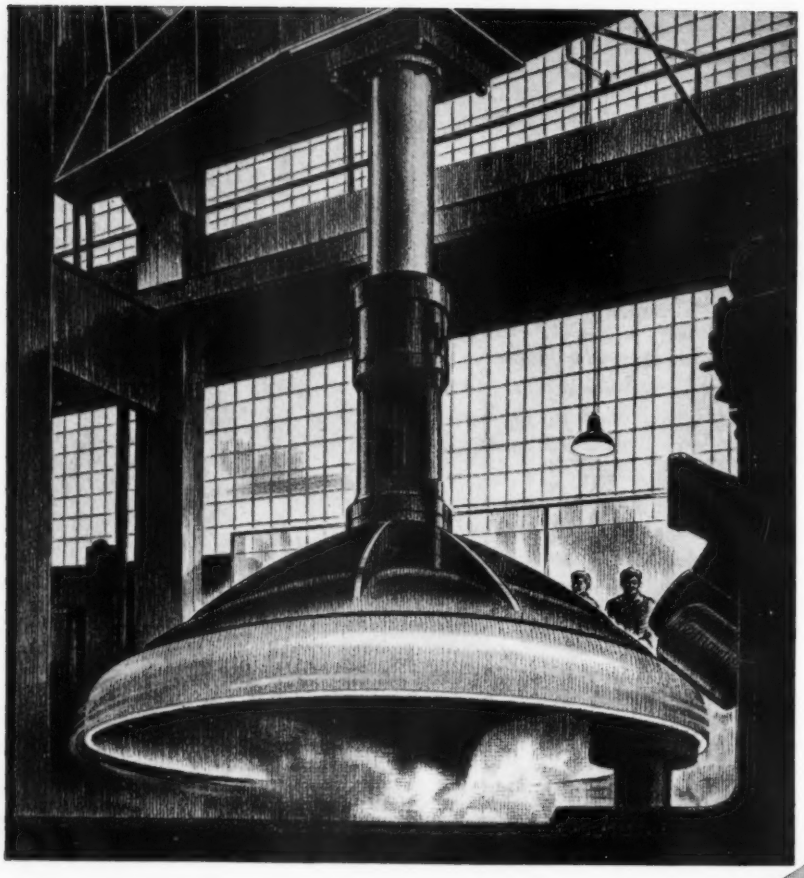
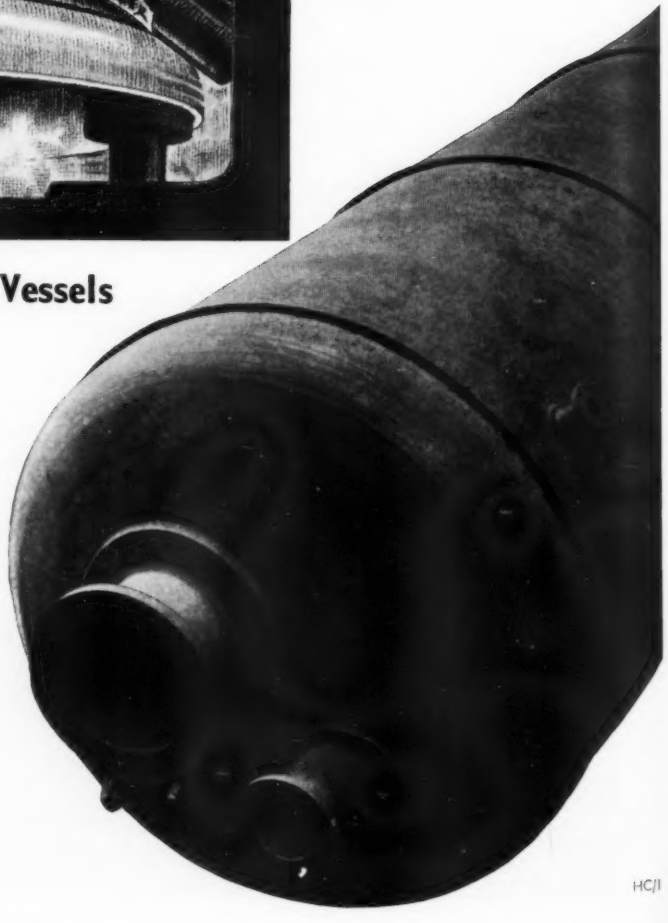
Spinning

SAVES METAL

—CUTS TOOL COSTS



The design and production of Pressure Vessels may be greatly facilitated by using dished and flanged ends spun by Harveys on the Rotarpress. They combine semi-ellipsoidal form with large knuckle radius. A substantial reduction in plate thickness can be effected, and in most cases tool costs are eliminated.



'Rotarprest' Ends for Pressure Vessels

can be supplied in Mild, Alloy and Clad Steels and Non-ferrous Metals. The capacity of the Rotarpress ranges from 5 to 15 feet diameter, and ⅜" to 4" thickness. Knuckle radii and depth may be varied to meet individual requirements.

Please ask for List No. NP 965 giving full range of sizes.

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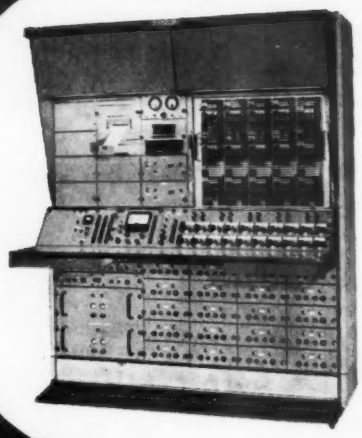

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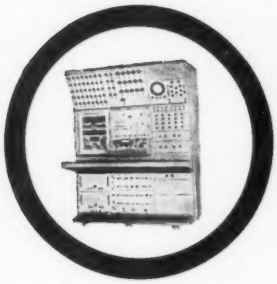
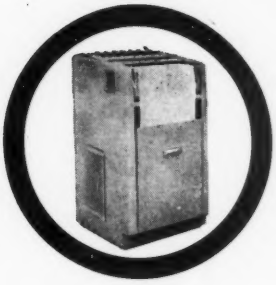
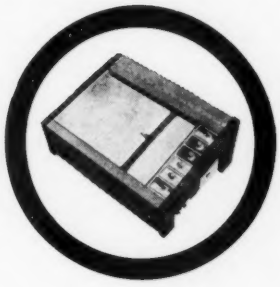


131 R Analog Computer



Eight Channel Rectilinear Recorder 1902-D.



Variplotter 1100-D.

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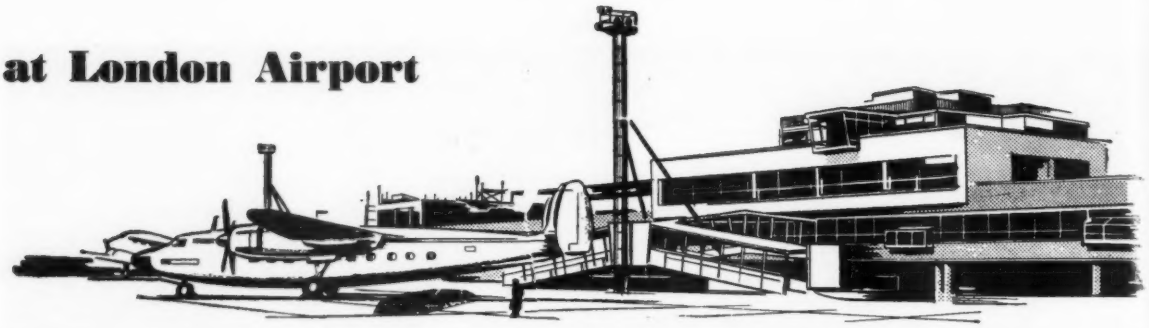

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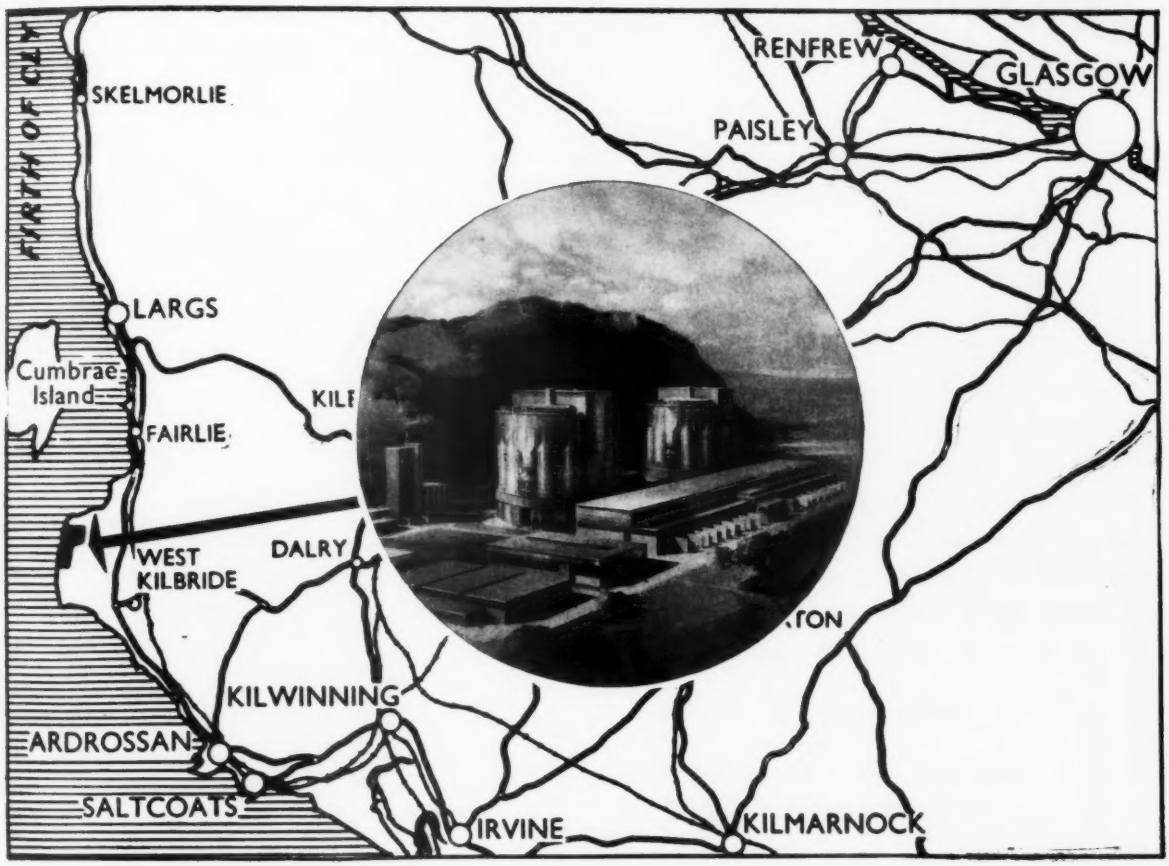

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Simon-Carves Ltd

SIMON ENGINEERING GROUP

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IN ASSOCIATION WITH THE GENERAL ELECTRIC CO LTD OF ENGLAND

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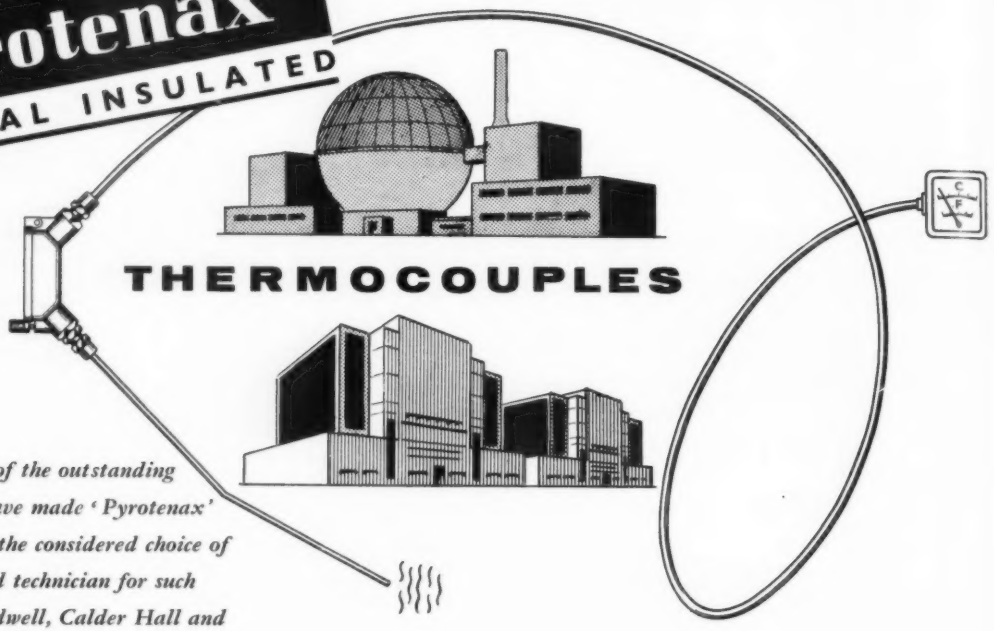
THERMOCOUPLES



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Full technical details in publication 31/X109.

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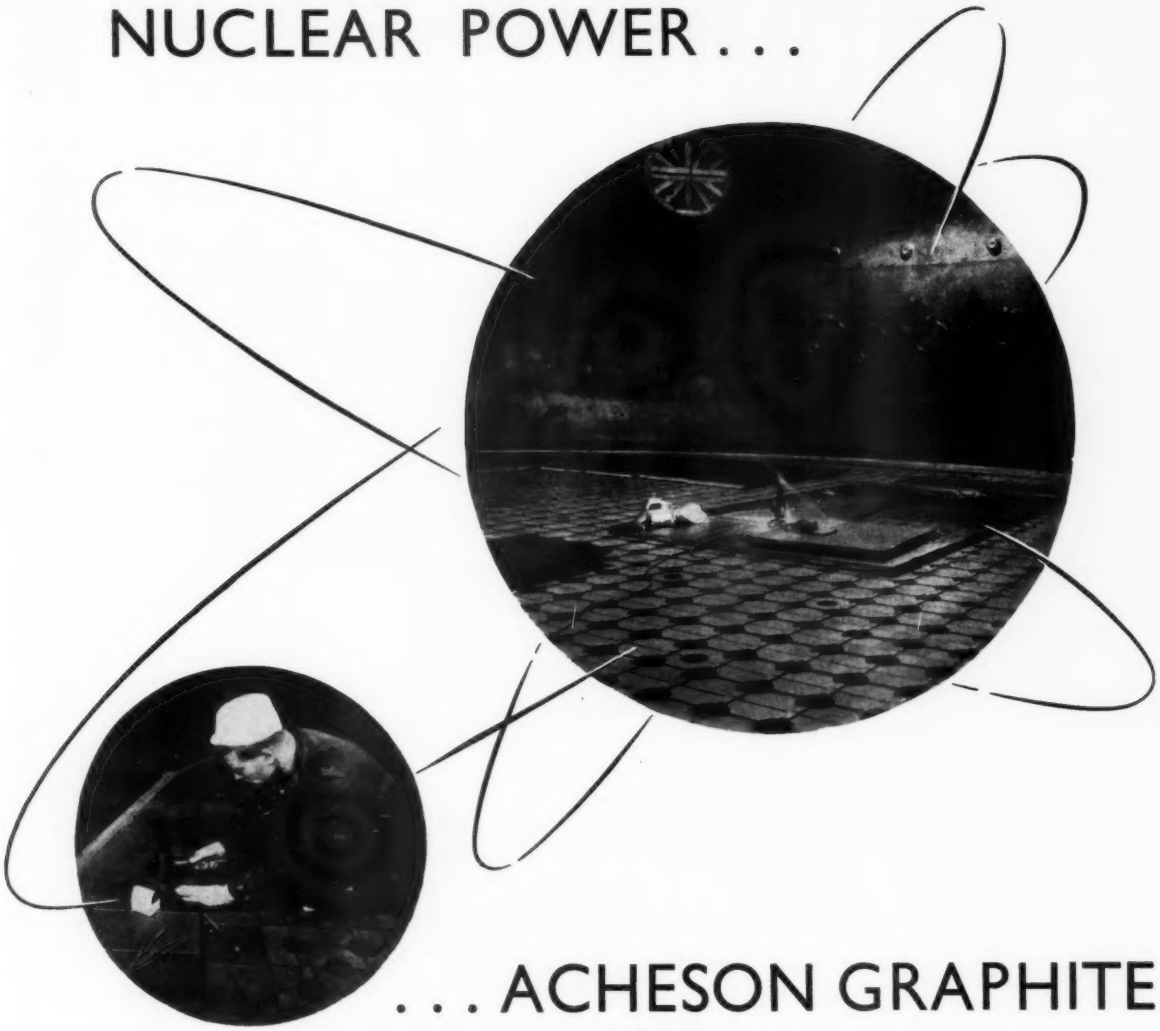
NUCLEAR POWER . . .



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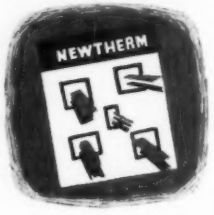

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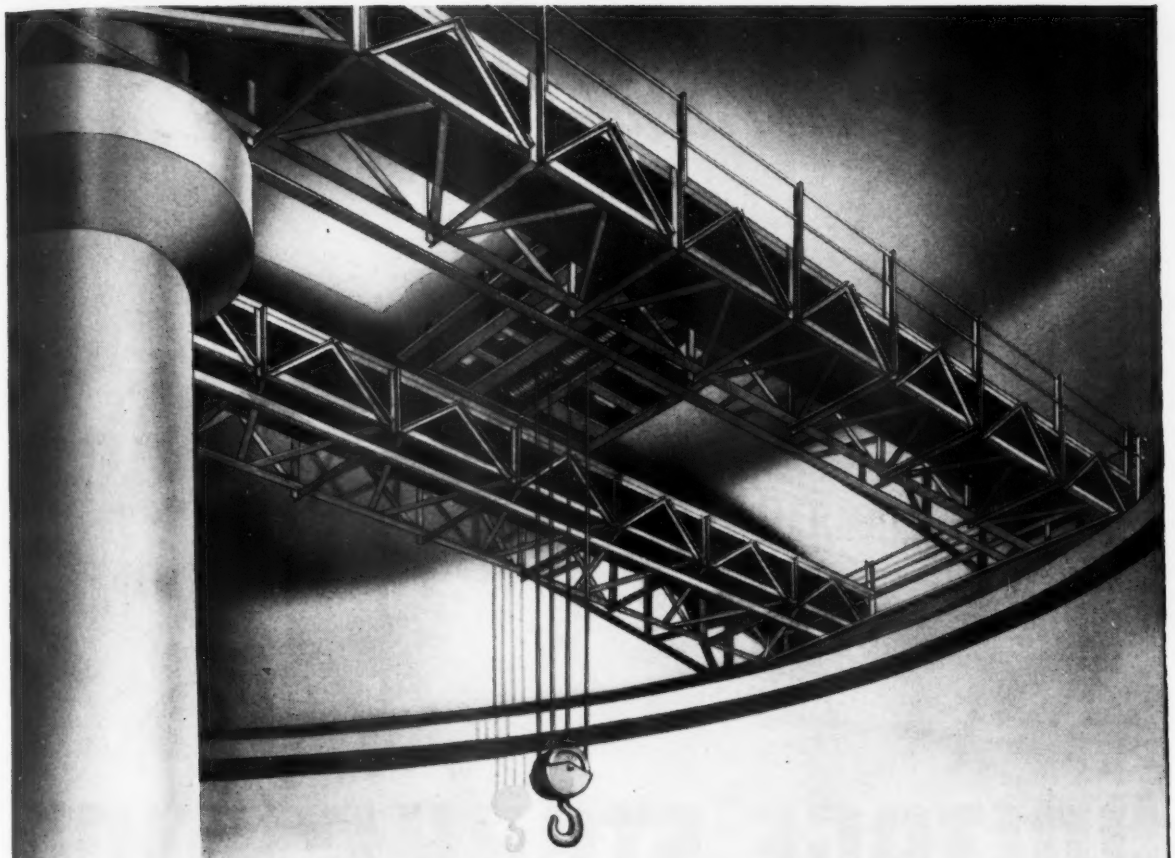

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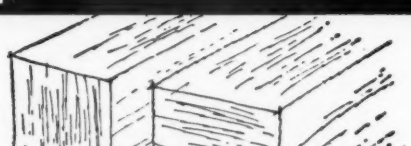

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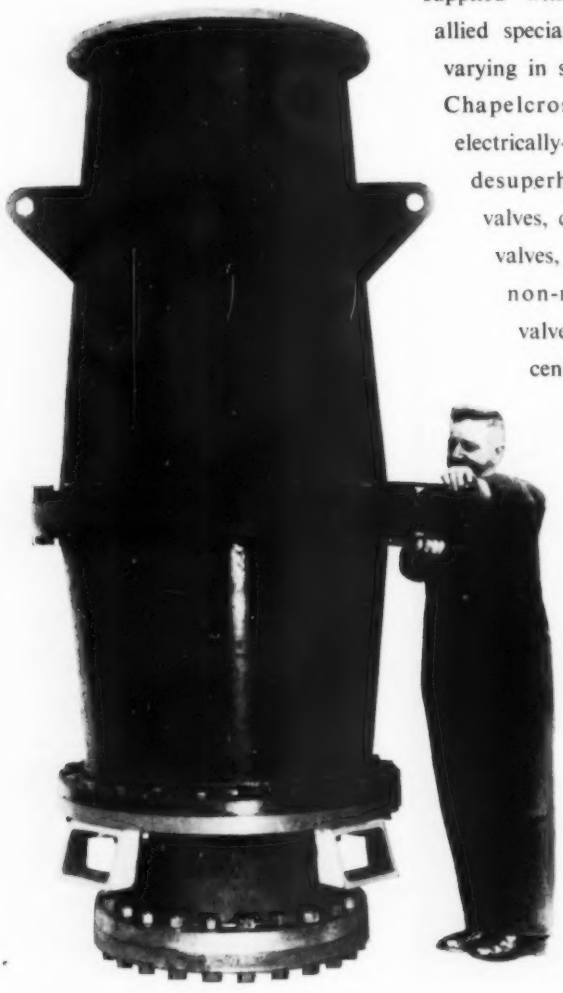
26 in. bore Parallel-slide Valve with electric control unit.



20 in. bore Deadweight Relief Valve.

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HUNTERSTON
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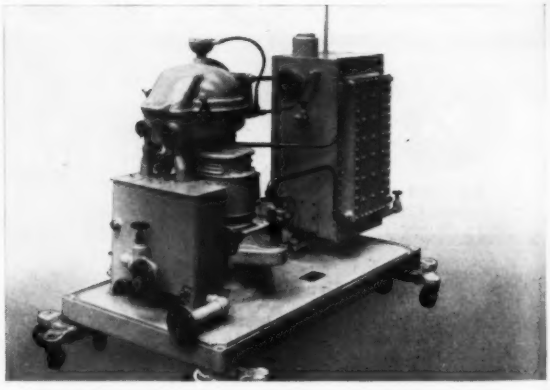

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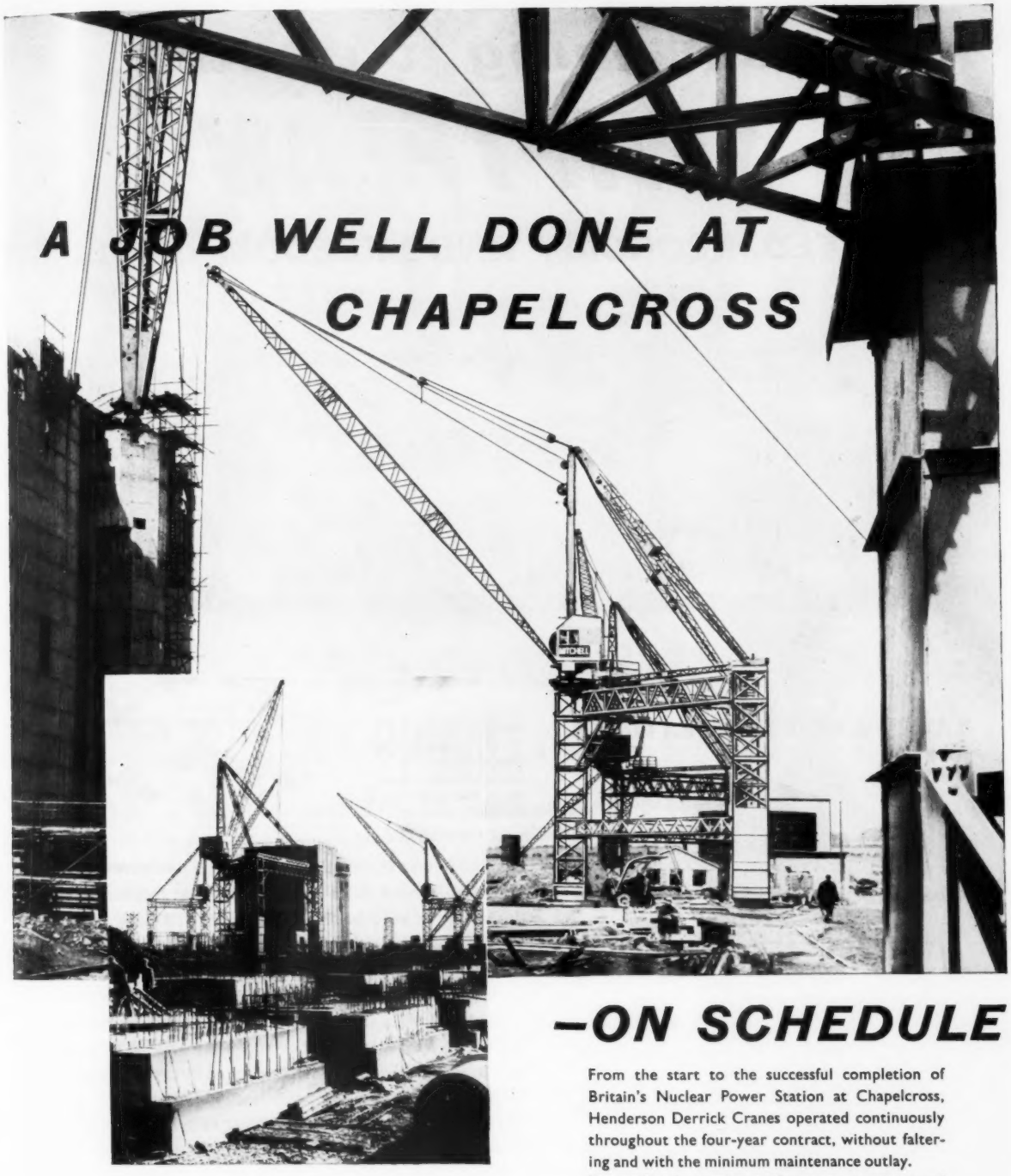

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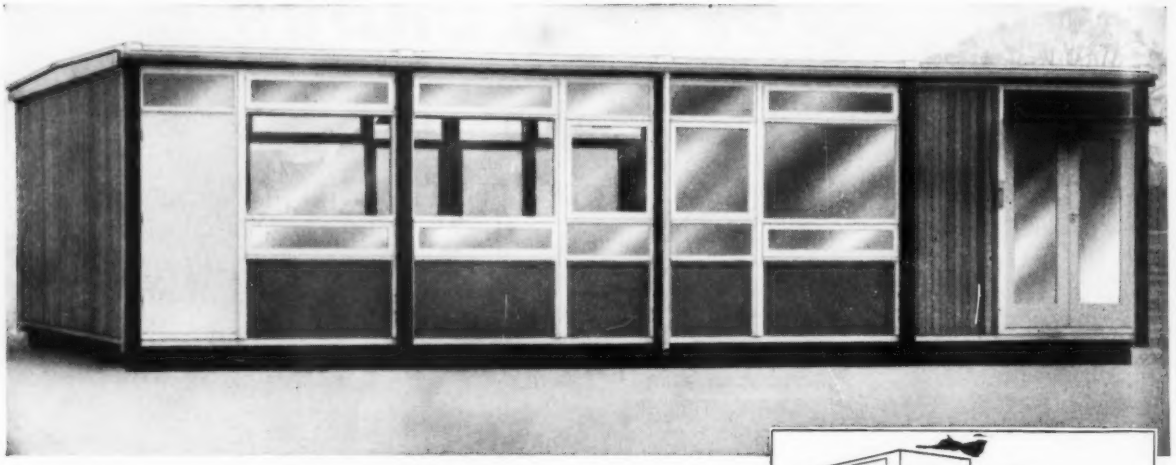

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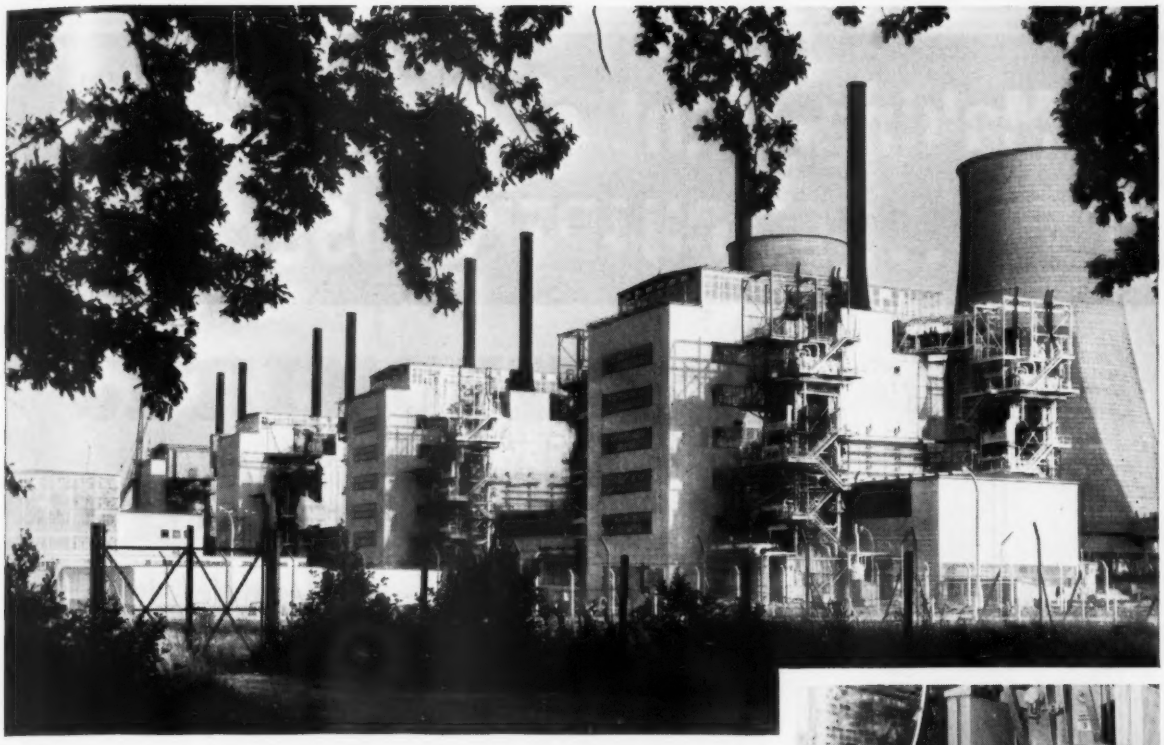

RIGHT: *Installing Henley single-core 33 kV cables in Turbine Hall Transformer Bays.*
BELOW: *Henley Control Cables rising to Reactor No.1 Control Panels.*

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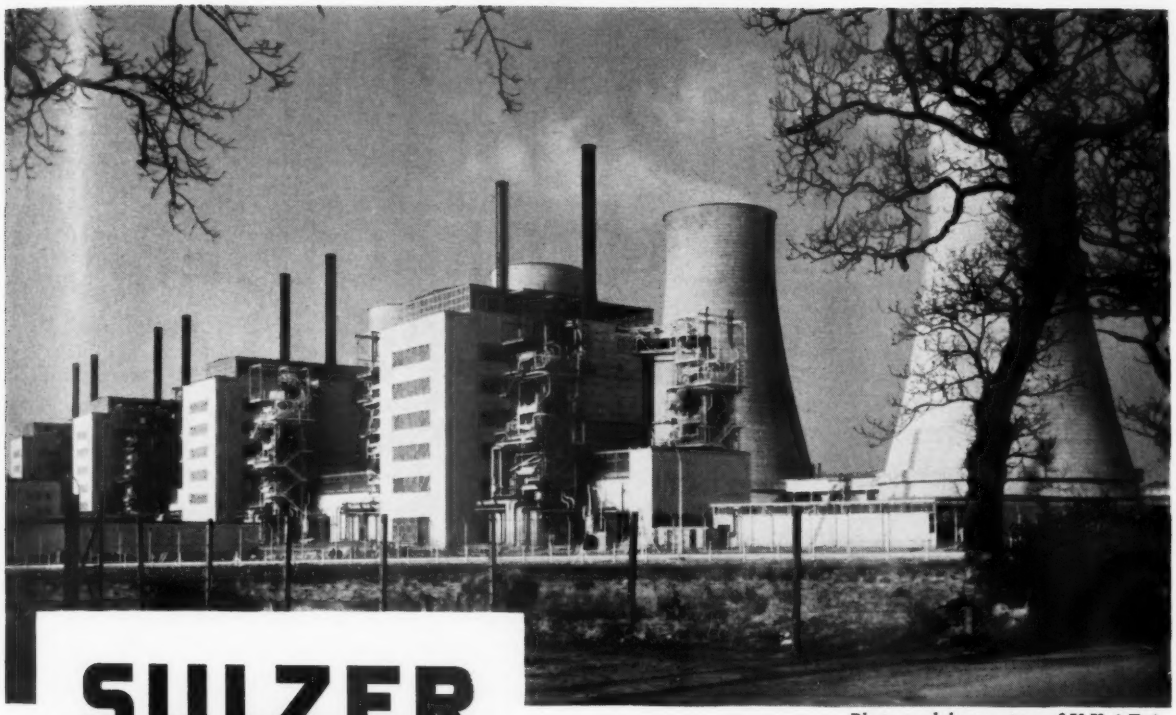

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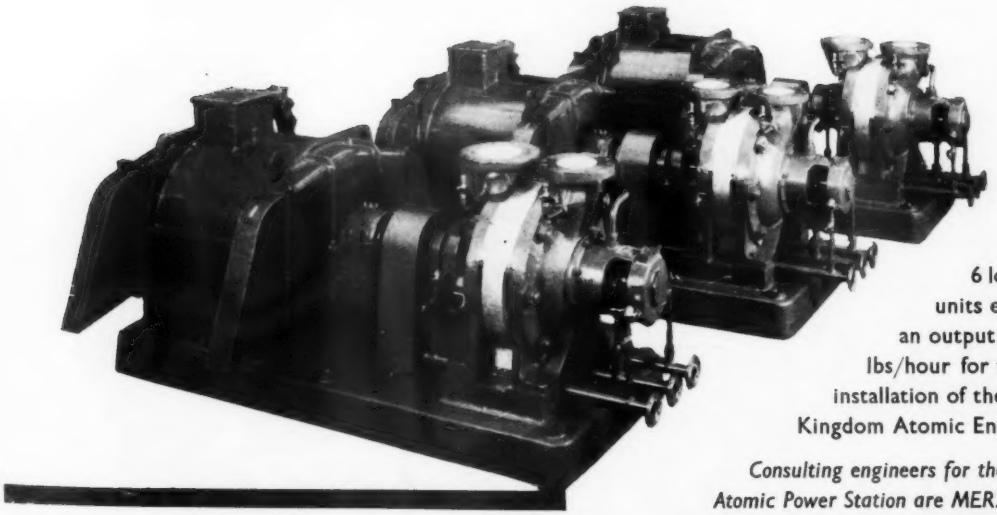

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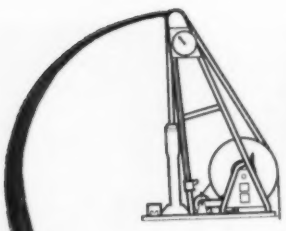

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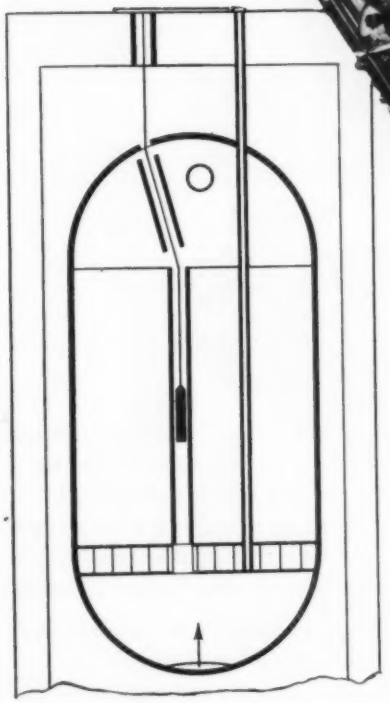

This console gives complete remote control of the camera. It carries the picture monitor and the control unit.

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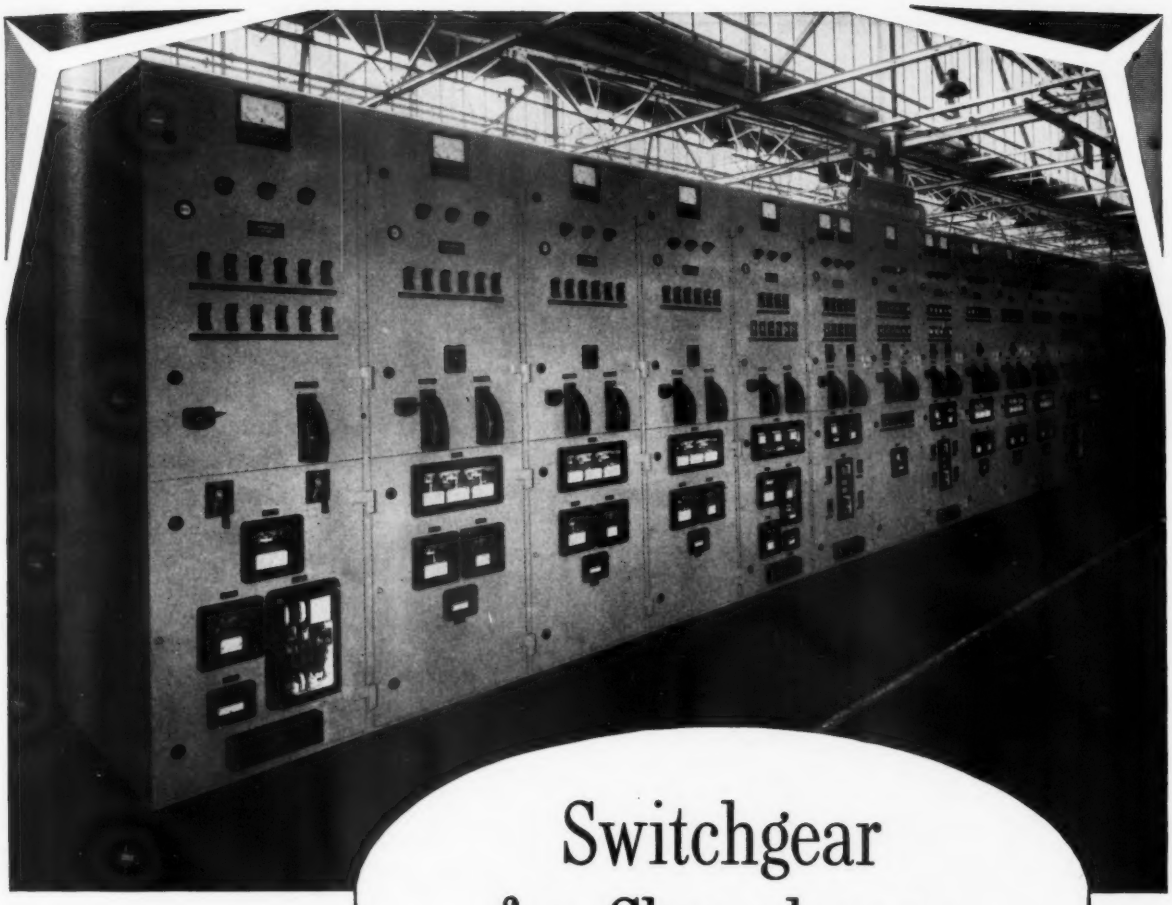

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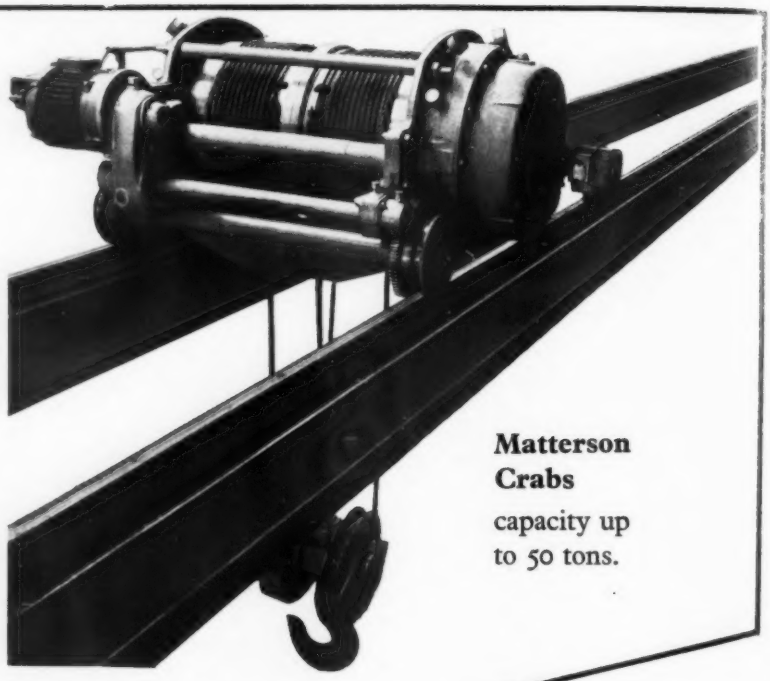

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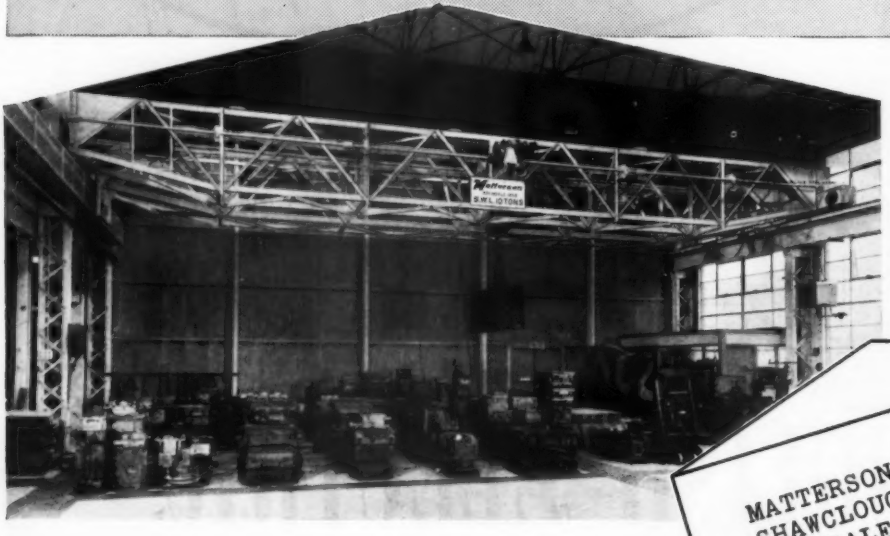

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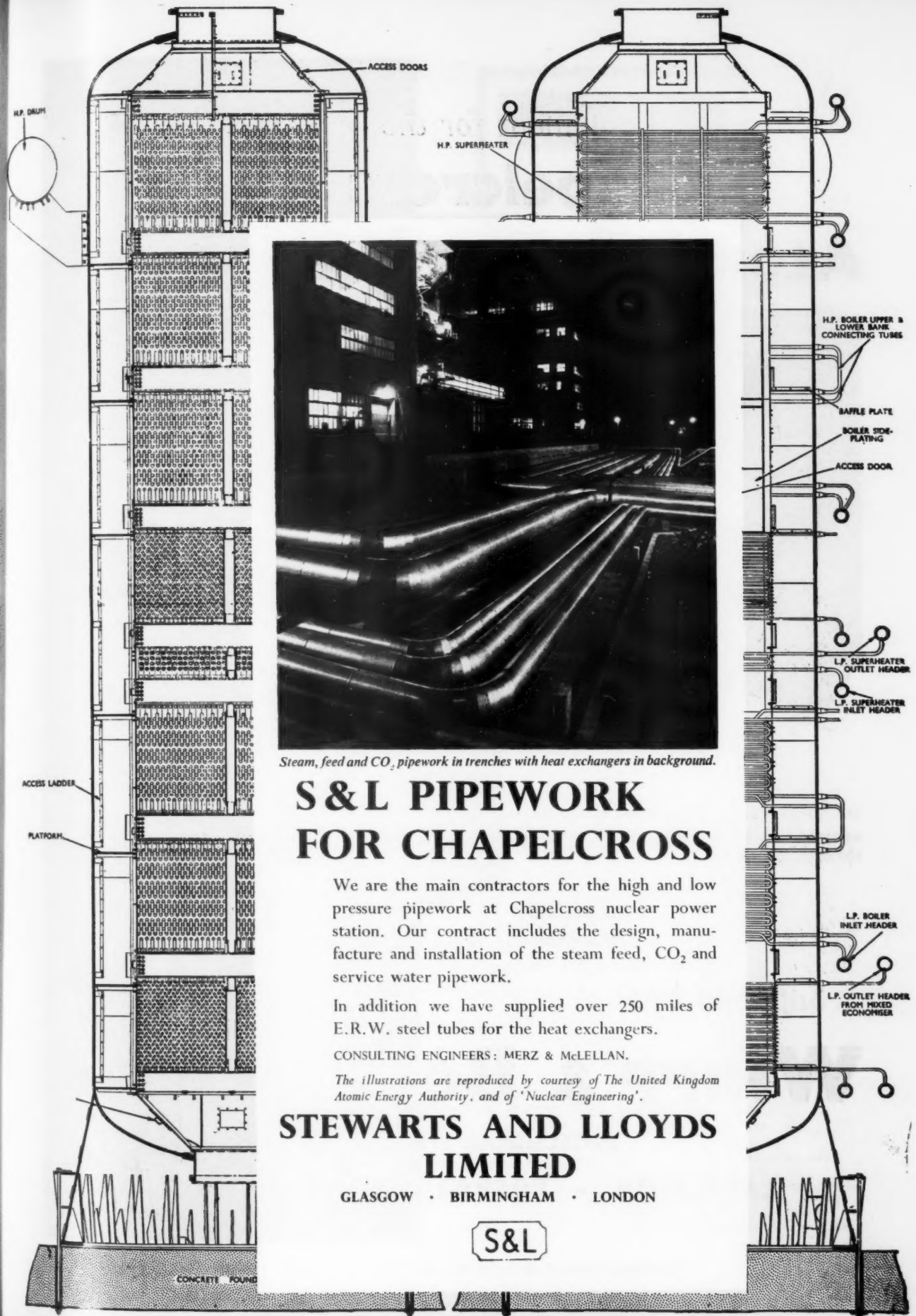

Steam, feed and CO_2 pipework in trenches with heat exchangers in background.

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CONSULTING ENGINEERS: MERZ & McLELLAN.

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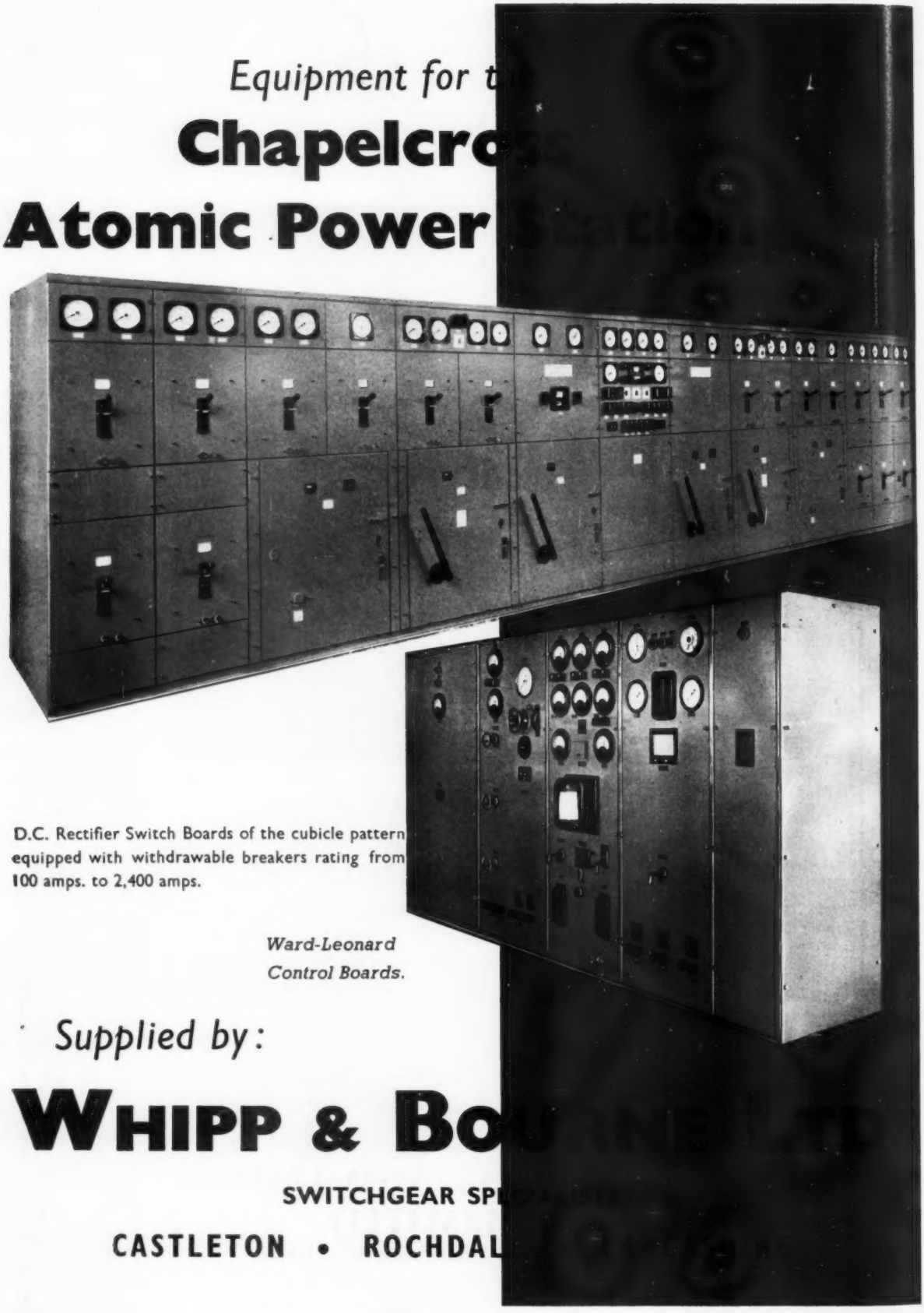

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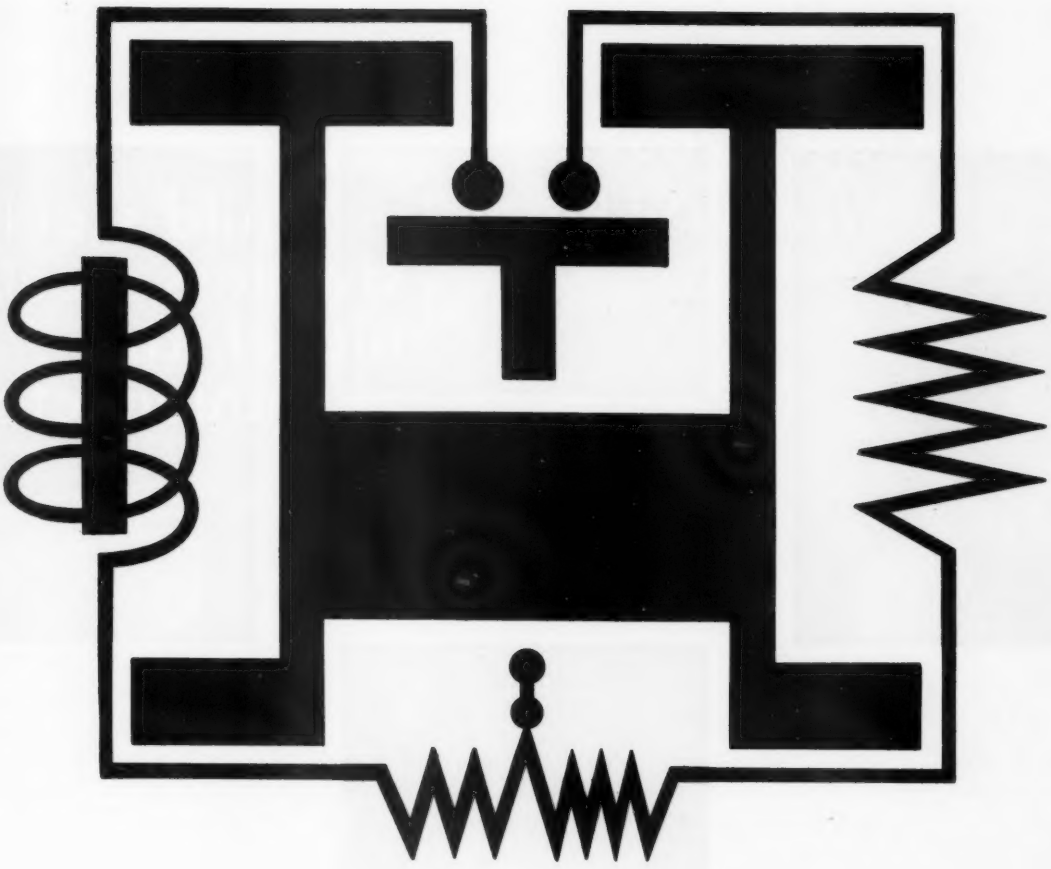

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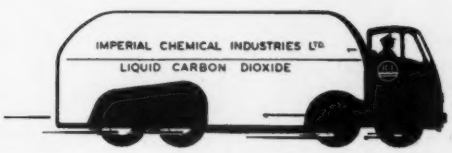

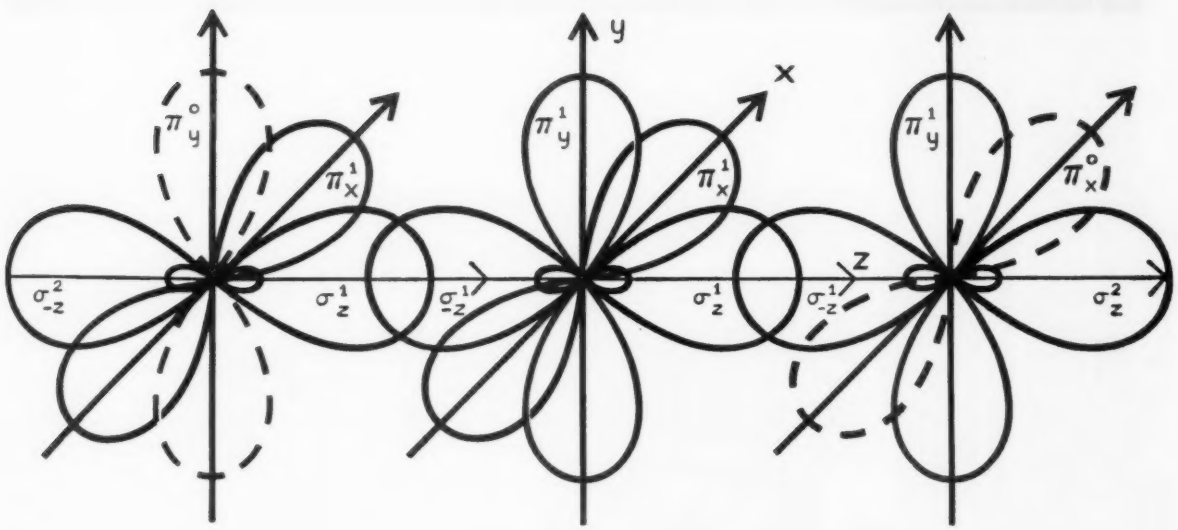

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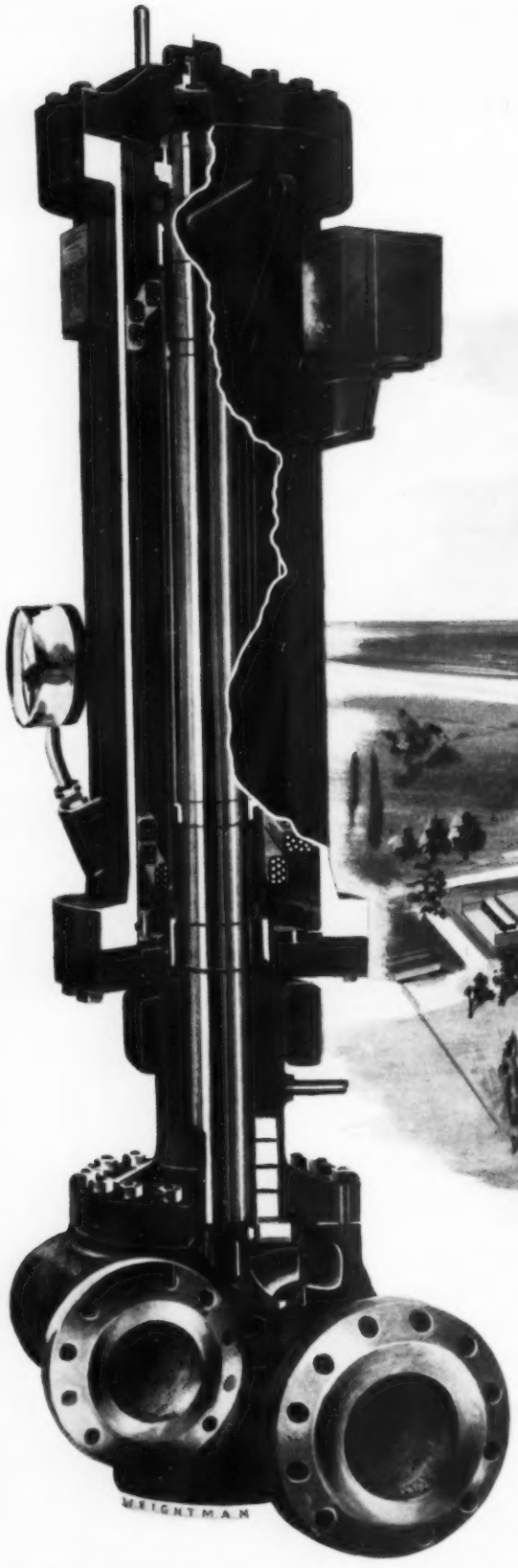

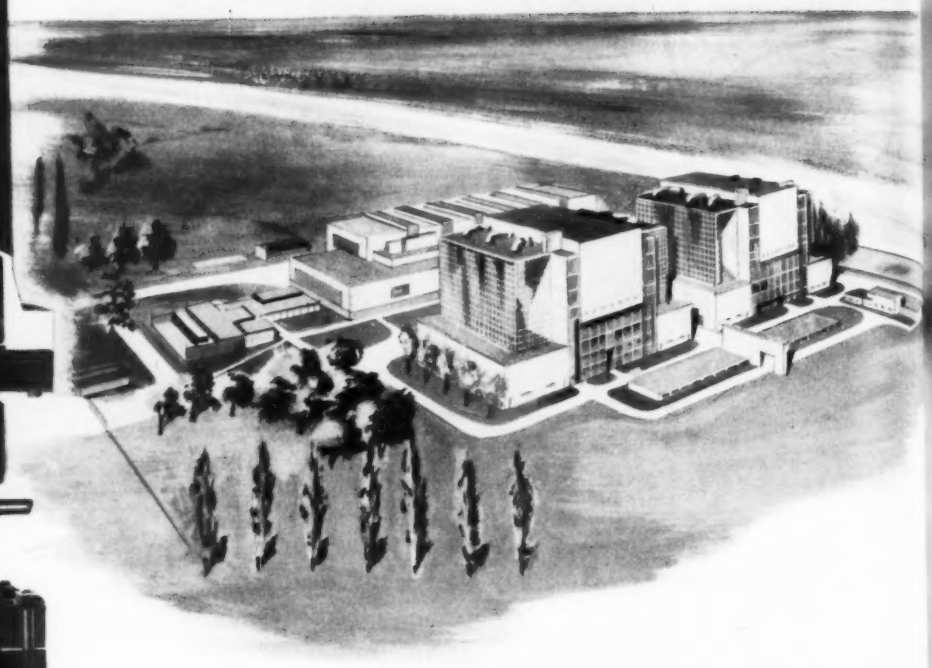

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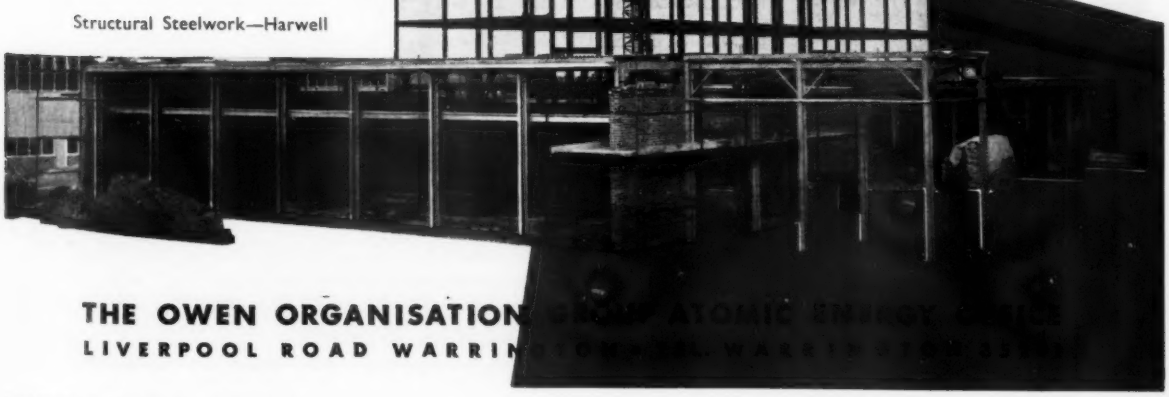

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SW/67

Nuclear Power

PUBLISHERS COLUMN

A stage in the programme

Although it received but scant attention from the National Press, the official opening of Chapelcross power station marked an important stage in our atomic energy history. True, it is virtually identical to Calder Hall and its power is not large compared with that of the more advanced CEGB stations now building. Nevertheless its 140 MW output is enough to supply a city about the size of Leicester and is far more than that of many coal-fired stations we thought so large only ten years ago.

When we learned that May 2 had been selected as the official opening day we immediately decided that Chapelcross should form the theme for our June issue. But there was a problem. As far back as July 1958 we had published an important article on construction aspects of the station by Mr. P. Knowles of Merz & McLellan, the Consulting Engineers in charge, together with a large coloured section view of the station. Clearly we could not go over the same ground again.

The passage of a year since that article had seen one reactor coming into commission, so what better than a follow-up article describing how this was done? We therefore approached Mr. D. R. R. Fair, the Works Manager at Chapelcross, with the proposition that he write one for us. To this Mr. Fair agreed, and the article duly appears in this issue.

When it came to a front cover, it had to be Chapelcross too, but we didn't want just another photograph. It occurred to us that so far no one seems to have shown graphically how far we've come since the Queen opened Calder on October 17, 1956, so we've attempted to do this. Of course the rise in output should be shown in steps as each reactor was brought on the line but we thought it was less confusing to smooth these steps out. By next spring Chapelcross and Calder together will be delivering 280 MW and a few months later Berkeley and Bradwell will begin to make their presence felt. A programme to be proud of.

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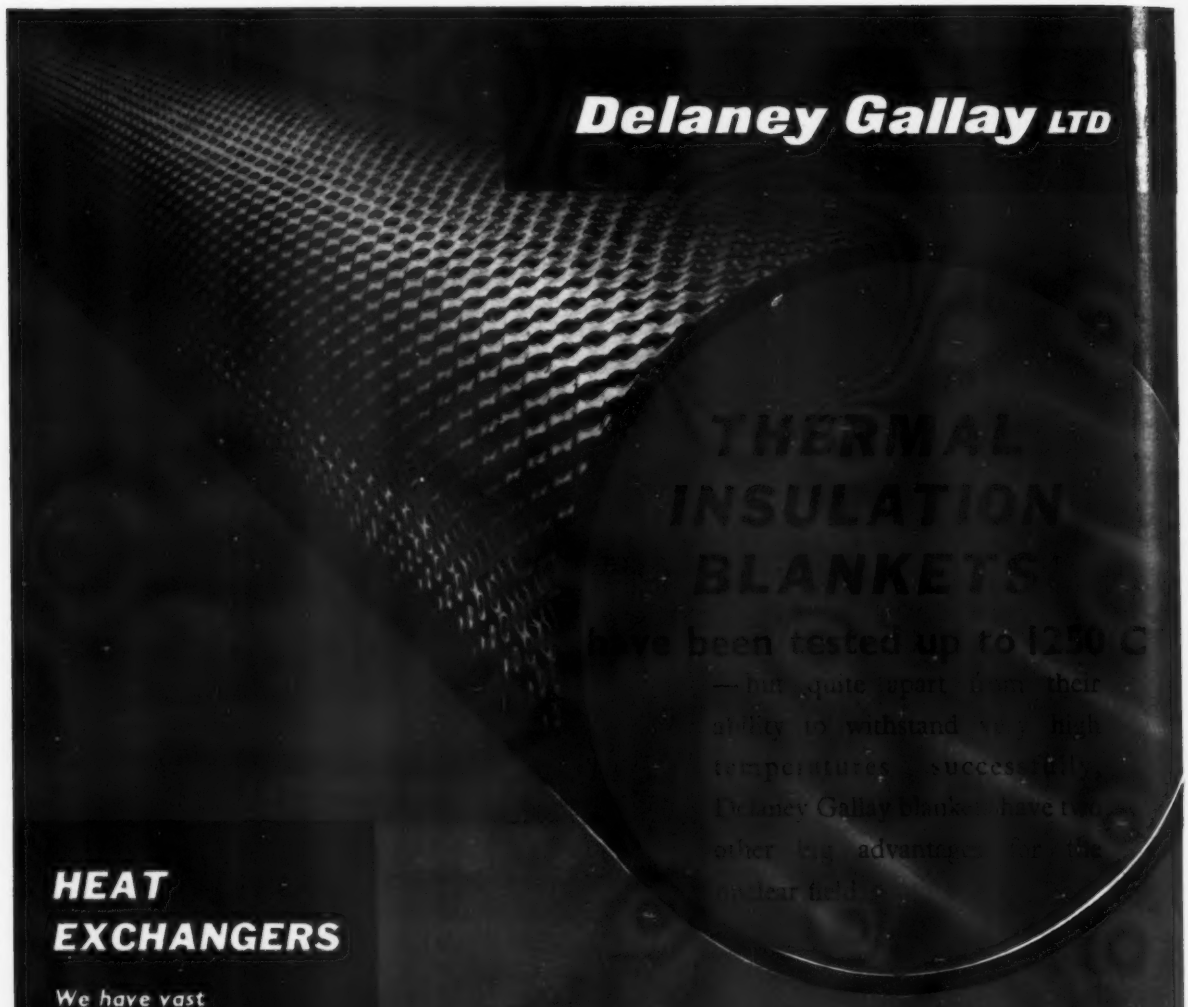

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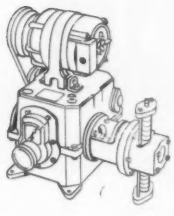

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The Editor welcomes correspondence for publication

Fuel element future

From the Head, Fuel Development Branch, Atomic Energy of Canada Ltd

SIR: If the 450 delegates who attended the Fuel Element Symposium described by Dr. Greenough in your April 1959 issue were polled, I would wager that virtually all would disagree with Greenough's summary statement that 'the general impression left by the colloquium is that in the immediate future the best elements are likely to be based on metallic fuels in metal cans.' I think most would simply substitute the word ceramic for metallic.

Another misconception is conveyed in the article by the subtitle 'Stainless cladding most popular.'* Outside of the UK, the sheathing materials most favoured for large-scale use in power reactors are zirconium alloys, *not* stainless steel.

The reference to development at Chalk River of stainless steel clad elements where the wall thickness is as little as 0·006 in. is erroneous. What was said was that zircaloy-2 clad fuel elements with a ratio of sheath diameter: wall thickness as high as 60 : 1 were being developed.

Chalk River, Canada O. J. C. RUNNALLS

** This subtitle was actually an editorial insertion, but it is an echo of the text.* *Ed.*

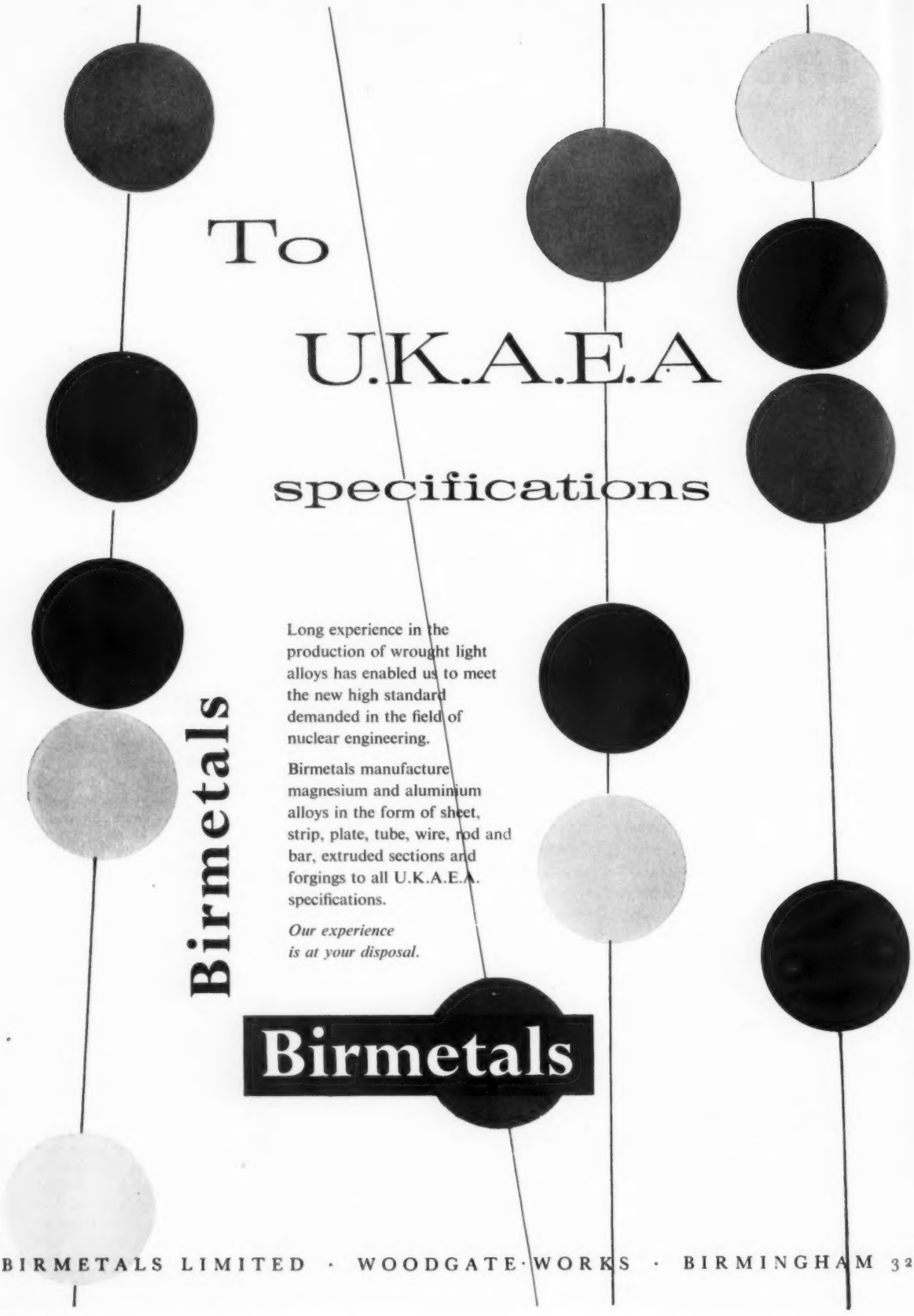
Pools and tanks

From the Director, Sodium Reactors Dept, Atomics International

SIR: I would like to attempt a rather more complete answer to the question, appearing in your April issue (*Sir* p 75), concerning the difference between a pool reactor and a tank reactor.

There should be no difficulty in distinguishing between the basic features of the two types, although it is true that there has been some confusion in the labelling of those on the market. The single distinguishing feature of the pool type should be the exposed free surface of the water pool, the depth of which provides the only shielding in the upwards. vertical direction. A very small pool type should not be called a tank type just because it is small, and any which uses a solid shield cover should be classed as a tank type. Of course this definition can get us into trouble if a cover shield is provided to be used at the discretion of the operators.

The logic of this definition arises from the limitation which the exposed pool surface places on the operating power level and the available neutron flux. The activation of trace impurities in the water and the N-16 activity produced from the O-16(n,p)N-16 reaction result in radiation levels above the surface of the pool which are excessive for power levels above one megawatt or so. This limits the maximum flux for pool types to a few times 10^{13} and consequently limits their utility and capability as truly research reactors. Pool types do permit some 'flexibility' (in the language of those who peddle this type) and do permit viewing of the Cherenkov glow but they cannot compete with higher flux tank types in their potential to support research programmes. Most certainly a lot of training can be done with pool types,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Like our famous contemporaries Heckles & Rowlock, we too are often misinterpreted. Our lot is even harder, however, for we do not manufacture straightforward things like tubes.
We could put it simply (and inadequately) by saying that we make the black stuff on the walls of your T.V. tube; that we have recently produced a conducting ink for postage stamps, a silver dispersion for the repeater valves of transatlantic telephone cables. We could say that and still overlook hundreds of other important uses for our products.
Although Dr. E. G. Acheson first manufactured colloidal graphite over 50 years ago, we admit there are still too many people who do not know about us. This is a pity for we are solving problems—electrical, electronic, metal-working, nuclear, for instance—in industry all over the world.
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SIR!

continued from p 83

some radioisotopes and activations can be produced, and some types of research problems can be pursued. But let it be recognized that anything which can be accomplished at low flux levels can be done much easier and faster at higher flux levels, and that the marginal or 'tough' research problems can only be done with the higher flux levels.

Those who are in the market for laboratory reactors should consider very carefully what it is they wish to do with them, in advance of placing their orders. It is one thing to wish to do training and to produce some low specific activity radioisotopes, and another thing to turn out significant research results.

I might close this lengthy note by saying that I believe it will not be too long before it is realized that mistakes have been made in the indiscriminate purchases of laboratory reactors. Many too many are installed without any well defined objectives beyond that of their prestige value in being able to say that the things exist. If someone, in each case, bothers to keep track of what is being accomplished by having the device around, I am certain that there are apt to be a host of disappointed people.

Canoga Park, Calif. MARVIN FOX

Boiling nomenclature

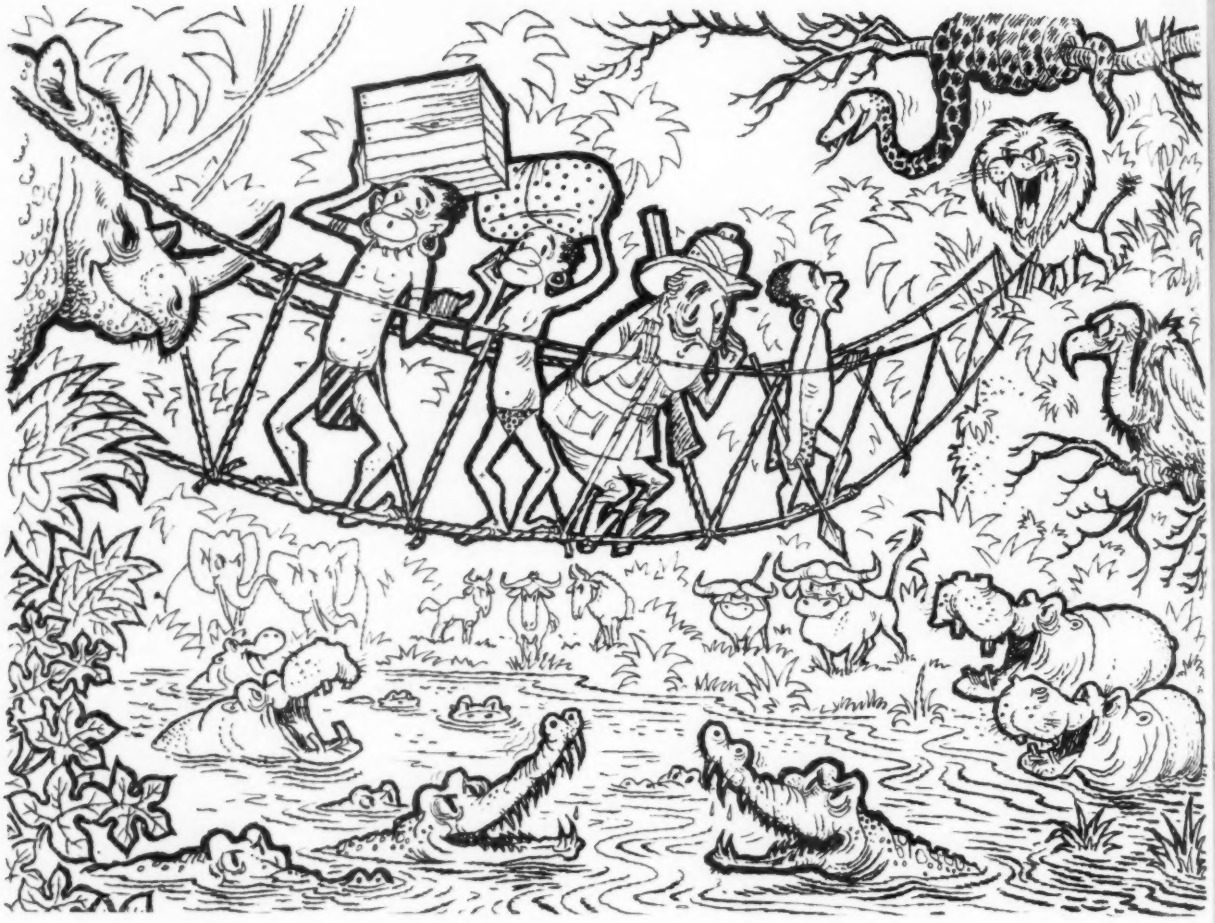
SIR: In reply to Dr. Patten's letter in your April issue, although it might be desirable to compare boiling heat transfer results with a standard nucleate boiling heat transfer correlation, it would be difficult to choose a universally acceptable one, considering the wide range of variables involved. Most western authors, on presenting their experimental results, refer to one or another of the better known correlations that we described in our later article on 'Boiling effects in liquid-cooled reactors' (NP February and March). This is probably the best solution at this stage.

We would agree with Dr. Patten on the desirability of presenting experimental boiling results on a linear plot when only a small section of the boiling curve is being investigated. Fortunately most authors already do this (e.g. Westwater and Santangelo, *Ind. Eng. Chem.* 1955, *47* p. 1605). The logarithmic plot, although useful when defining the boiling regimes, can be misleading in that it disguises the sharpness of the heat flux peak and this is presumably why Dr. Patten is reluctant to accept the term 'critical temperature difference.' In fact, if the boiling curve shown in our original article (NP January) is replotted on a linear scale, the heat flux has a very sharp maximum defining the 'critical temperature difference' to within about 5°F for the particular set of experimental conditions.

We take this opportunity of adding one further point to our original discussion. Translations of Russian, German and other foreign language reports on boiling would be more comprehensible if the terms suggested in our paper were used instead of the literal rendering of the original.

H. A. ROBERTS
A.E.R.E., Harwell R. W. BOWRING

▶ *There was a misprint in Dr. Roberts' reply to Dr. Gambill's letter in* Sir *last month. The maximum burnout heat flux quoted should, of course, have been* $54{\cdot}8 \times 10^6$ *Btu/ft²h and not* $54{\cdot}8 \times 10^{-6}$ *Btu/ft²h. Ed.*



'GOING CRITICAL'

In building up a reactor, the nuclear fuel is added until the supply of neutrons from fission of the uranium balances the losses by capture and leakage. Beyond this critical stage, a self-sustained chain reaction starts.

It was the metallurgist who discovered how to produce uranium in manageable forms, how to sheathe it without wasteful absorption of neutrons, and how to fabricate metals for the control rods which discipline the activity of the reactor. In other words, the metallurgist is responsible for the reactor "going critical" with a minimum weight of fuel, and for its reliable, safe operation for long periods.

No organisation has done more towards solving the metallurgical problems of nuclear engineering than I.C.I.

Fifteen years ago, I.C.I. Metals Division produced Britain's first fabricated uranium. Today, the technical resources and practical experience of the Division are geared to meet the increasingly stringent demands of a major industry.

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Nuclear Power
REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION
JUNE 1959 VOLUME 4 NUMBER 38

The World Bank speaks

THE COMPETITION LAST YEAR for Project ENSI, the 150 MW nuclear power station in Southern Italy, was the first ever held in which tenders for several different reactor types were invited. To evaluate these, the World Bank, which sponsored the project, appointed an eminent panel of experts drawn from Canada, USA, Italy, France and the UK. Their findings have now been published in a summary report which is probably the frankest and most realistic comparison yet made of the reactor systems involved.

The summary is a heavily blue-pencilled version of the full report, which is being withheld on commercial security grounds, but it makes very interesting reading nevertheless. The reactors proposed all remain anonymous except the successful IGE design, but the disguise is fairly thin and it is possible to identify most of them. The Panel grouped the reactors into two main types—natural-uranium, gas-cooled (3 British, 1 French) and enriched uranium (2 pressurized, 2 boiling, 1 organic)—and finally chose the IGE boiling water system. On all counts, however, one of the British designs (referred to in the Report simply as GC-1 but understood to be the GEC's design) came a very close second, being actually slightly better on overall unit costs at interest charges under about 6–7%.

On the gas-cooled reactor in general the Report is encouraging, rightly pointing out the very much lower fuelling costs obtainable. For the three British designs, which differed from each other by only a few tenths of a mill, this came to about 3 mills/kWh. The French design (Alsthom) apparently had a considerably greater fuelling cost but made up for this to some extent by a lower capital cost.

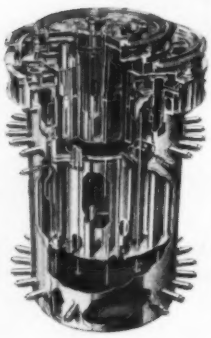
From the report it appears that the figure of 3000 MWd/t, generally accepted in this country for the burnup obtainable with magnox-canned natural uranium, is somewhat pessimistic. If axial shuffling is a practical proposition—and we can see no reason why it should not be, provided the design of the fuelling machine is right—it seems that 4500 MWd/t can be achieved, and even more if radial shuffling is possible as well. This is on reactivity considerations, but it is thought that this burnup might well be approached before swelling becomes serious. A possible figure of 4380 MWd/t is mentioned. If this is indeed the case it is going to throw new light on CEGB reactor economics.

Two of the gas-cooled tenders (one of them GEC) proposed a hollow fuel element which, on paper, gave indications of higher power output and burnup. The report mentioned that a substantial irradiation programme on such elements is now in progress in the UK, since it is intended to use them in future plants. The Panel appears to have been highly impressed with the GEC's system of fuelling from below and considered this would enable both axial and radial shuffling to be carried out expeditiously. One way in which the gas-cooled reactor is at a disadvantage compared with enriched types is in the number of operating staff required. The Panel's comparison showed a difference of about 60 which, they say, could amount to about 0·2 mill/kWh. The organic-moderated reactor, however, would be even worse off owing to the staff needed for operating the clean-up system.

The Panel discussed at length the uncertainties in calculating the reactivity of GCR's and found that in some cases a reduction of output might have to be tolerated for a few months while the reactivity of the initial fuel loading is increased. They also say that some of the original control systems were considered unsatisfactory and that modifications would be necessary to cope with possible asymmetric flux distributions. However, the Panel had little doubt that these could be made without much difficulty.

The most significant finding about the water-moderated types is the rejection of stainless steel—proposed as cladding by all the US tenders except IGE—owing to the poor neutron economy resulting. The successful IGE design uses 1·84% enriched oxide in zircaloy-2 with a guaranteed burnup of over 13,000 MWd/t. An interesting point in this connexion is the Panel's remarks on cobalt production from nickel in the steel. This subject was recently discussed by Dr. Zinn in this magazine and the Panel considered the problem could be 'quite troublesome' in boiling systems. Surprisingly, of the enriched systems only the IGE design included means for burst slug detection and the Panel regard the satisfactory development of this as of the 'highest priority.'

THE FIRST FAST BREEDER NUCLEAR REACTOR.



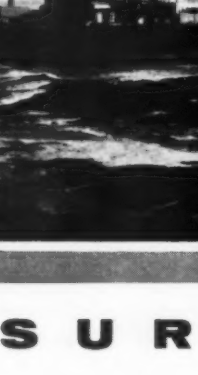
U.K. Atomic Energy Authority's Fast Reactor at Dounreay, where John Thompson have built the reactor vessel and complete heat exchange plant.

The most complicated stainless steel vessel ever made, the 45 ton reactor vessel.

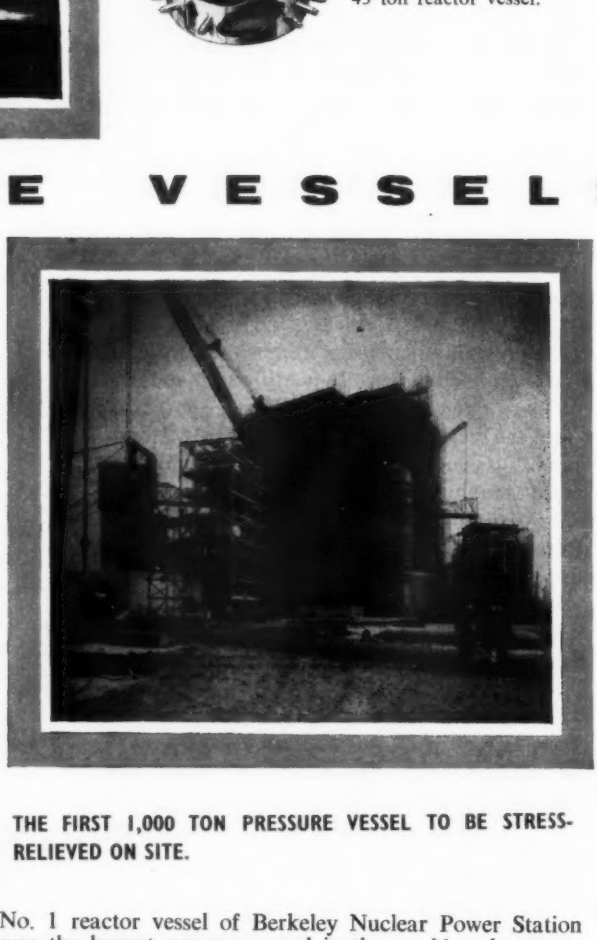
PRESSURE VESSELS

THE FIRST COMMERCIAL NUCLEAR POWER STATION.

The Central Electricity Generating Board's first commercial Nuclear Power Station at Berkeley, Glos.



One of the 16 heat exchanger vessels 70 ft. 6 in. diameter and weighing 133 tons.



THE FIRST 1,000 TON PRESSURE VESSEL TO BE STRESS-RELIEVED ON SITE.

No. 1 reactor vessel of Berkeley Nuclear Power Station was the largest pressure vessel in the world to be stress-relieved. Weighing 1,000 tons and being of 80 ft height and 50 ft diameter, the stress-relieving operation was carried out by John Thompson Limited, of Wolverhampton, who were responsible also for manufacturing and erecting the vessel.

Pictured (foreground) inside the reactor vessel is the 165 tons diagrid, fitted with heaters and busbars for the stress-relieving operations, which was carried out strictly in accordance with B.SS 1500.

Heaters and busbars can also be seen (background) climbing the 45 ft high walls of the reactor vessel.

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A26a

Worldview

the month in atomic energy

BRITAIN TO BUILD NUCLEAR SHIP

Eight proposals include advanced reactors

During the first two weeks of May, British nuclear and marine engineers showed the Government that they were just awaiting the order to go ahead. The United Kingdom AEA and seven industrial organizations submitted their reports and recommendations to the Galbraith Committee. Supporting these design studies, an exhibition was held by the Admiralty so that members of the Government and naval officers could have the opportunity of studying models, design details and test rigs and of discussing the various features with members of the design teams.

The eight reactor systems are of very varied types and they all possess different characteristics in terms of size, weight, capital and operating costs and other technical factors. Between them, they represent designs that have been built, adoption of existing designs and some that, as yet, have not been built at all. Gas cooling appears to be the preferred type—the AEA, de Havilland Engine Co. and the GEC Atomic Energy Group proposing various forms of this type. Next favourite was the boiling water type, designs for this coming from AEI/John Thompson Nuclear Engineering Co. and Mitchell Engineering/Fairfield Shipbuilding & Engineering Co. A pressurized water reactor system was put forward by Babcock & Wilcox and two new and interesting projects came from Vickers Nuclear Engineering Group and the Hawker Siddeley Nuclear Power Co.—a steam cooled heavy water project and an organic liquid moderated reactor respectively.

Difficulties of assessment

Not all of these projects are equally advanced for early use and three of them rely on designs originally initiated in the United States. With all these variables no direct comparison can be made and the Galbraith committee is setting up a technical sub-committee as early as practicable to judge which system offers the best advantages, balanced against the time required to complete building. At the same time the Civil Lord's (Galbraith) committee will investigate means of financing the first ship and examine the capital and operating costs. Parallel with the work of these committees, the Ministry of Transport Committee on Marine Nuclear Safety will continue its review of the problems of safety in nuclear ships and the port installations they will visit when operating. These assessments are being treated with urgency but because of the scope of the investigations necessary, it is anticipated that it will be some two months before the Galbraith Committee will be in a position to recommend to the Government which proposal will be most suitable to achieve the aim of an economic nuclear merchant ship.

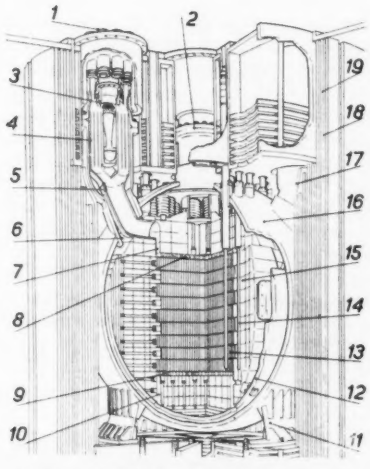
The Gas Cooled Types

The AEA have not revealed details of their design but say that it is similar to the Advanced Gas Cooled Reactor, AGR, at present being built at Windscale and doubtless advantage will be taken of the Dragon project at Winfrith Heath as well. For economic marine use it is anticipated that materials of construction and methods of control and fuelling will have to be extensively modified. **The de Havilland Nuclear Power Group** have the same ideas as the AEA and have proposed a High Temperature Gas Cooled Reactor, HTGR, aimed at meeting both naval and mercantile marine requirements. Against lack of operating experience, the interest being shown in the US and West Germany, as well as this country, is put forward.

The HTGR design is centred on the use of an all ceramic core permitting safe operation in excess of 1000°C. The fuel used is a mixture of uranium 235 and thorium in ceramic form bonded into graphite pellets, which in turn are contained in sealed impermeable graphite blocks. Helium, at 1000 lb/in.² circulates through a large number of coolant holes in the core and transfers the heat to six boiler units, projecting above the reactor pressure vessel. The large temperature difference between fuel and steam, normal for naval machinery 850°F–600 lb/in.² results in a high core heating rate, small boiler size and low pumping power loss. Two reactors working together are envisaged, giving a gross thermal output of 150 MW and would weigh 2400 tons. The integration of the boiler-circulator units with the pressure vessel results in a compact plant layout and enables a secondary containment vessel to be fitted inside the main biological shield of laminated iron and water to reduce weight. The estimated cost for the first production unit, less core fuel blocks, is some £M1·4 for a 150 MW output, being approximately £28 per s.h.p. Low fuel cost results from a low initial investment, 67 kg U-235, and the long core life, expected to be between 400 and 650 days at full power.

De Havillands stress that this HTGR possesses a large development potential in that the reactor output can be doubled by increasing the pumping power, circuit pressure and fuel temperature. The core life can be extended to something like 20 years by the substitution of beryllia for graphite as the moderator and the capital cost would be significantly reduced if gas turbine power plant was employed. No refuelling equipment has been included in the design or estimates for this design.

In the **General Electric Atomic Energy Group's** design stress was laid on effi-



U/TH CARBIDE FUELLED. The de Havilland 75 MW High Temperature Gas-cooled Reactor (HTGR) estimated to cost £28/s.h.p. including boilers. The main components are
1. Boiler water inlet and steam outlet connexions; 2. Refuelling machine access; 3. Gas circulator; 4. Boiler; 5. Boiler inlet duct; 6. Boiler outlet duct; 7. Core gas outlet duct; 8. Core gas outlet chamber; 9. Core gas inlet chamber; 10. Core gas inlet duct; 11. Pressure vessel support skirt; 12. Support structure; 13. Core; 14. Control rod; 15. Graphite reflector; 16. Primary pressure vessel; 17. Secondary containment vessel; 18. Shielding water; 19. Shielding plates

ciency for marine applications utilizing a well-tried gas-cooled graphite moderated reactor and may be likened to a compact Calder Hall reactor on its side. The fuel elements are, however, of a new design, consisting of slightly enriched uranium dioxide canned in stainless steel. The reactor has a gross thermal output of 150 MW, producing about 50 MW of electrical power and weighs only 2400 tons, including fuel charging equipment. An interesting feature of this proposal is that the CO_2 required, is generated from fuel oil. This, with the ability to refuel at sea, greatly increases the mobility of the vessel.

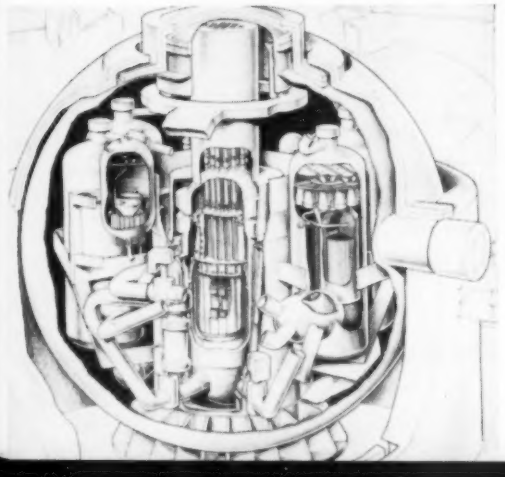
As the GEC unit is based on current technology of British reactor systems, it could be rapidly put into operation without much additional development. The first reactor of this type is estimated to cost about £M3 and assuming that the reduction in fuel requirements would make some 5000 tons of additional carrying space available, the costs per ton mile carried would be comparable with those for conventional thermal plant. It is expected that, with advances in design, these costs can be still further cut.

American BWR designs

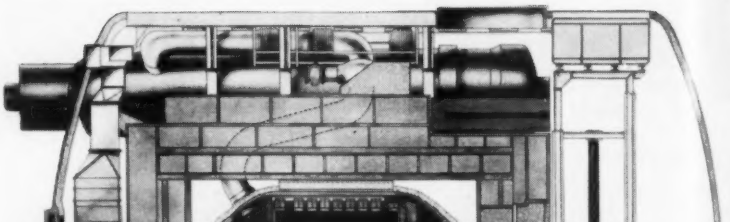
Both the Boiling Water Reactors, BWR, proposed are derived from American designs. **The AEI-John Thompson Nuclear Energy Co.** puts forward a natural circulation direct cycle BWR based on the United States General Electric Co.'s experience. The reactor has a thermal power of some 160 MW, fuelled by zircaloy canned enriched uranium oxide and has an estimated endurance at full power without refuelling of 380 days. A particular feature of this design is that the reactor pressure vessel is of the banded type. The primary circuit has a nominal pressure of 1000 lb/in.² at 286°C producing in the secondary circuit, at the steam drum outlet for propulsion purposes, saturated steam at 1000 lb/in.². Such a reactor would weigh only 1600 tons complete and could be made ready for use in 2½ years. On a basis of fuel cost per s.h.p., nuclear fuel is cheaper in that oil costs ·384 pence per s.h.p. hour while nuclear fuel charges would only be ·290 pence per s.h.p. hour. An advantage of this design is that it can utilize plutonium as and when the United Kingdom AEA make this material available for commercial uses. The American BWR marine project was reviewed in detail in NUCLEAR POWER last month.

For the first reactor of this type AEI/John Thompson propose that certain core components would be purchased from the American GE but, subsequently, the entire unit would be constructed in the UK.

The other BWR proposal, by **Mitchell Engineering Co. & Fairfield Shipbuilding Co.** is based upon the American design of Combustion Engineering Inc. The reactor, fuelled by enriched uranium stainless steel clad, has a thermal output of 156 MW. The primary circuit works at 950 lb/in.² and 538°F, producing steam for the propelling machinery at 650 lb/in.² at 496°F. The design of the reactor permits operation at 80% full power for a period of about 3½ years. No attempt could be made, nor would it be necessary, to handle the fuel elements at sea but to obtain uniform burn-up, 'shuffling' of the fuel elements should take place at 12 to 15 months intervals, during annual refit. Such a unit would be suitable for a 25,000 s.h.p. vessel and could be produced ready for sea trials in three years.



IMPROVED PWR. The Babcock & Wilcox 180 MW pressurized water reactor is designed to give a power output 2½ times greater than that for the NS 'Savannah,' occupying only 20% more space



HORIZONTAL CALDER. A longitudinal section through the improved version of the GEC Atomic Energy Group's 150 MW marine reactor. The core is in the centre surrounded by the water biological shield. Control rods enter from the left and the fuelling machine is on the right; standpipes lead from it to the horizontal fuel channels in the core. At the top is one of the four steam-raising units, with its hot gas duct

Improved 'Savannah'

Babcock & Wilcox Ltd have submitted plans for a pressurized water reactor, PWR, which is based upon the plant now being constructed by the Babcock & Wilcox Co. of America for the N.S. *Savannah*, but by intensive development the unit will have a power output 2½ times greater with only a 20% increase in space occupied by the American prototype. Safety and reliability are the keynotes of the design and the reactor has a thermal output of 180 MW when using enriched uranium dioxide clad in either stainless steel or zirconium. The unit would weigh approximately 3000 tons and could be made ready for sea, from plant wholly manufactured in the UK and with a guaranteed output, in 2½ years. Depending on the type of fuel element employed and the source from which it is obtained, the cost of fuel would be between ·3 pence and ·6 pence per s.h.p./hour.

Steam-cooled concept

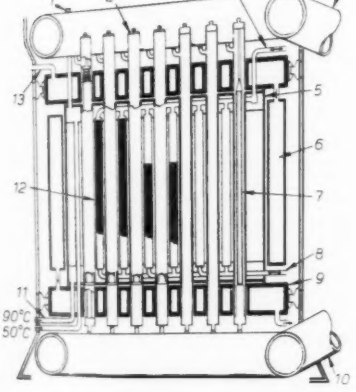
To provide a purely marine plant, **Vickers Nuclear Engineering Ltd** have proposed a unique design. The reactor, of 150 MW, is heavy water moderated steam cooled and fuelled by low enriched uranium oxide canned in stainless steel. The project, directed by Dr. S. G. Bauer, incorporates thermo-compression of the dry steam for cooling; this method utilizes only 10% of the energy required by equivalent mechanical compressors. Control is by level changes of the heavy water moderator and there are no moving parts in the reactor core. The only moving parts outside the core but within the containment shell are canned heavy water circulating and control pumps, control and isolating valves and primary circuit feed pumps. All have been designed to fail safe without immediate external control action. Liquid control enables the reactor to operate without damage irrespective of the pitching and tossing of the vessel. An additional safety

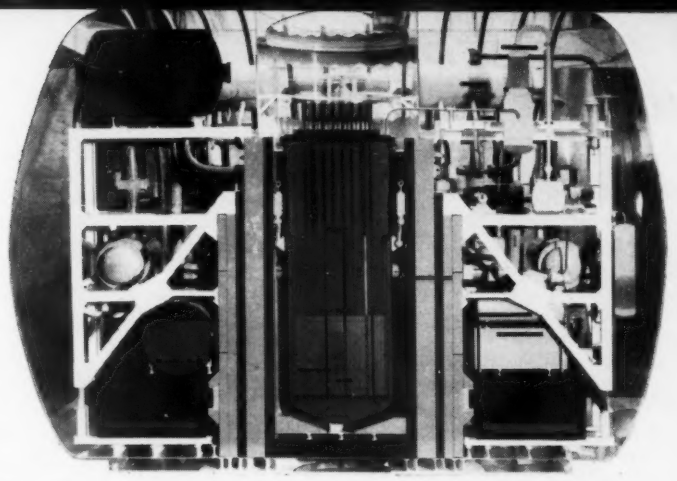
factor is that the fuel cans are located in aluminium tubes placed inside stainless steel tubes and between the two tubes there is a helium blanket. The reactor output is at 600 lb/in.² and 970°F providing steam at 420 lb/in.² and 850°F giving 46·5 MW net thermal output. An interesting feature of the fuel charging machine is that it has been found practicable to employ a standard Vickers gun mounting and loading mechanism and it was only necessary to change the materials of construction. With the exception of fuel element testing and critical assembly work, the Vickers Group can make the whole of this British design and through the employment of existing technology, prolonged development and testing will be unnecessary. The complete plant is estimated to weigh 2100 tons. The weight may be reduced and turbine efficiency raised at a later date by omitting the secondary steam circuit with its heat exchangers, when open cycle operation is proved possible.

British OMR design

The **Hawker Siddeley Nuclear Power Co.** has proposed the only UK design for an organic moderated reactor. The reasons for the selection of this type is that it is essentially simple and comparatively small in size. These properties result in a system pressure of less than 100 lb/in.² and the utilization of mild steel in the construction of the reactor vessel and primary circuit. The liquid coolant, terphenyl, is non-corrosive and has a low vapour pressure. Enriched uranium dioxide fuel elements canned in stainless steel

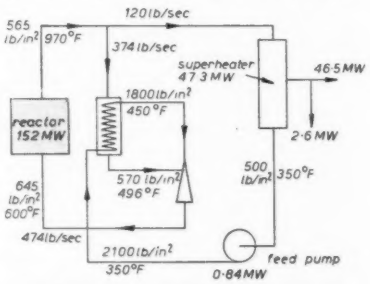
MOVING PARTS ELIMINATED. In the core of the Vickers 150 MW heavy water-moderated steam-cooled reactor there are no moving parts. The core comprises of
1. Connexion to header tank; **2.** Fuel charge tubes; **3.** Helium on D_2O free surface in control tubes; **4.** Steam outlet; **5.** Aluminium calandria; **6.** Water reflector; **7.** Fuel element; **8.** Control D_2O; **9.** Aluminium diagrid; **10.** Steam outlet; **11.** D_2O moderator cooling circuit; **12.** Control tubes; **13.** Reflector cooling circuit





SIMPLICITY IS THE KEYNOTE FOR BRITISH OMR. Sectional model of Hawker Siddeley's reactor which has a net thermal output of 56 MW. The construction is very largely of mild steel and the pressure is only 100 lb/in.² in the reactor vessel, making for low capital and running costs. The superheaters, evaporators, liquid level and drain tanks are located outside the shielding but within the main containment vessel

are proposed. The reactor has a net thermal output of 56 MW, providing steam at 480 lb/in.² and 710°F, with an overall cycle efficiency of 24·8%. The plant, weighing about 1300 tons, would



THERMO - COMPRESSOR CIRCUIT. Vickers initial design—it is hoped that an open cycle operation may prove possible when the secondary steam circuit will be eliminated

cost approximately £890,000. The OMR of such an output and suitable for a 40,000 ton tanker would have operating costs about 5% higher than those for a conventional unit. With development and plutonium enrichment, however, Hawker-Siddeley are of the opinion that the operating costs of such an OMR unit would be some 5% less than those of a comparable conventionally powered ship.

The future

The importance of these proposals and the responsibility of the Galbraith committee cannot be over-estimated. The designs are all based on operating costs closely comparable to those experienced with conventional powered vessels of the same power but the decision will have to give a lead to a particular type of reactor and indicate whether it is considered better to employ a purely British design or take advantage of American 'know-how.' As R. A. Linden, technical director of Aktiebolaget Götaverken, said at the recent Engineering & Marine Exhibition 'once an economical marine nuclear power unit is built, there will be a landslide to this form of propulsion by the merchant navies, if only for prestige.' A worthwhile solution would be to treat these proposals in two groups, one for immediate building and one for long-term development, and then select one design from each group and proceed immediately with the necessary work.

Nuclear medicine centre planned

The Royal Marsden Hospital at Sutton Downs, Surrey, is proceeding with its plans for the first UK establishment devoted to the application of nuclear energy in medicine. The Ministry of Health has approved the project and building will begin as soon as Treasury approval has been given. The scheme is estimated to cost more than £M1, of which £600,000 has been allocated by the Ministry of Health and £200,000 from the hospital's endowment funds. The aims of this establishment will be two-fold; to provide a radiation treatment centre—and develop the medical study of isotopes and treatment of patients with radioactive isotopes. Eventually, it is anticipated, that courses in the practical use of radioactivity in medicine will be run.

Harwell visitors

During his state visit, the Shah of Persia went to Harwell on May 7 when he was shown both the Dido and Zeta installations.

At the end of April, six Russian experts on controlled fusion work spent three days at Harwell and visited the laboratories of Associated Electrical Industries at Aldermaston before taking part in the Thermonuclear symposium in London.

Worldview

INTERNATIONAL

Greater freedom

The agreement for cooperation between the United States and the United Kingdom, which has been in force since August 4, 1958, has now been amended. This amendment enables additional exchanges of equipment and materials to be made, broadens the scope of the cooperation and serves the common defence arrangements in which the two nations jointly participate. In this way, each nation will be able to supply the other with nuclear materials it is best placed to produce and will prevent unnecessary duplication of plant and effort.

Closer cooperation

Following the UK-Euratom agreement, signed February 4, a continuing committee to supervise the operation of the agreement has now been set up. It will provide a forum for consultations and for discussions on the possibility of additional arrangements for cooperation. It will consist of a UK Minister and the Chairman of the AEA and the Chairman and another member of the Euratom Commission. The continuing committee will be assisted by a technical committee which will shortly hold its first meeting.

Far Eastern tour

Headed by Dr. Harold Smith of IAEA's Division of Isotopes, a mission left Vienna on May 16 for a tour of Taiwan, Japan, Korea, the Philippines and Viet-Nam. It will study and discuss further possibilities in atomic energy work, with special reference to the installation of reactors, availability of raw materials and problems of power generation.

Missions to Latin America

Two other IAEA missions will be sent to Argentina, Brazil and Venezuela during the second half of 1959. In Argentina the missions will advise on mining and processing uranium ores and the possibilities of economic nuclear power generation. Brazil is interested in receiving advice on all aspects of their nuclear energy programme, with special reference to power production. While in Venezuela, the mission will give particular consideration to the development of programmes in connexion with the research reactor at present under construction (see *Worldview*, April 1959).

Materials agreements signed

On May 12, agreements of cooperation with the International Atomic Energy Agency by the United States, United Kingdom and the Soviet Union were signed in Vienna. These agreements implement earlier promises of assistance and establish the terms of supply of fissionable materials in accordance with the laws of the individual countries and the statute of the Agency.

Dragon Director named

The European Nuclear Energy Agency's Dragon project will be directed by C. A. Rennie of the AERE, Harwell. Chairman of the board of management is Dr. Sigvard Eklund of Sweden and the chairman of the general purpose committee is Dr. Jules Guéron, representing Euratom.

Users and builders meet

Euratom arranged, on May 8, a meeting in Brussels at which 30 producers of electricity and some 50 representatives of nuclear equipment manufacturers discussed the implementation of the US-Euratom agreement. While the electricity authorities were interested in the proposals, they expressed concern that the type of reactors to be constructed under

BELGIUM. Nuclear equipment is now becoming one of Belgian engineering activities and this stainless steel reactor vessel base, fabricated by Ateliers de Construction de la Meuse, shows the high standard being achieved

the programme ran the risk of being made obsolete by the rapidity of new technical advances. The constructors, on the other hand, indicated their confidence in the types which they considered well tried. The Commission stated that, in its opinion, 150 MW capacity nuclear power stations offered the best possibilities for industrial experimentation. In view of the opinions expressed, Euratom agreed to investigate the possibilities of making the agreement more elastic.

Cook speaks at Stresa

An absorbing interest in nuclear energy and a determination to bring about the practical realization characterized the spirit of the European Nuclear Energy Agency's Industrial Conference on Nuclear Energy held at Stresa, Italy, from May 11 to 14. Over 500 delegates from the US and most of the European countries attended the Conference, which was the third of its kind organized by the OEEC—previous ones being at Paris and Amsterdam.

Representatives of all the British nuclear groups were present and several of the papers were presented by them. Sir William Cook, AEA member for Engineering & Production, spoke on the opening day, and disclosed that Calder Hall has now produced over a thousand million units of electricity. He placed high hopes in the AGR and mentioned a figure of 10,000 MWd/t for stainless steel clad elements. On beryllium canning he would not commit himself.

Material transfer

With the IAEA acting as intermediary, the Institute of Nuclear Physics in Prague has agreed to supply a quantity of irradiated uranium oxide, free of charge, to First Chemical Institute of the University of Vienna. This material is required for a research project on the factors controlling the distribution of fission products in the biosphere and is being carried out by Dr. Thomas Schoenfeld of the Radio-Chemistry Department.

CENTRAL AMERICA

Puerto Rico gets first reactor

The first atomic reactor to operate in Central America was shipped on April 30 to Mayaguez, Puerto Rico, by Atomics International. This 10 W, solution-type laboratory reactor scheduled to start operations this summer, will be run by the University of Puerto Rico for the United States AEC and will be used for training and research purposes.

FRANCE

First feed-in

On April 22 the electrical output from the G2 reactor at Marcoule was, for the first time, fed into the French National Grid. This reactor was operating at a thermal power of 130 MW and produced 9 MW of electrical output. In subsequent days the thermal power of the reactor was progressively increased until achieving the full designed power output of 30 MW. This is the first nuclear power plant in Western Europe to supply electricity for consumer purpose.

ITALY

SELNI-Westinghouse agree

On April 16 Società Elettronucleare Italiana (SELNI) issued a contract to Westinghouse Electric International Company for a pressurized water reactor. It will be installed in the Italian company's Enrico Fermi nuclear power project in Northern Italy and is scheduled to begin operations in the spring of 1963. During the protracted negotiations solving both

commercial and technical problems, the power of the plant has been increased from 134 MW to 160 MW and it is expected that this project will prove to be the most economical in initial cost and operation of any plant of this type so far developed. This PWR, using enriched uranium, will operate as a 'base load' plant for Edison Group's power network and bring the total nuclear power output in Italy up to 510 MW, by early 1963.

Navy's nuclear centre

Negotiations are now in hand between the Italian Navy and the American Machine & Foundry Company for a 3 MW swimming pool-type of research and training reactor. This unit, operating on enriched uranium, is to be installed near Leghorn at the Navy's Centre for the military application of nuclear energy.

SOUTH AFRICA

UK export possibilities

Electricity production costs in the Cape Province are now higher than those for Calder Hall and providing British manufacturers can offer 30–60 MW nuclear power stations, Mr. A. J. Stroud, former UK Trade Commissioner in Johannesburg, said there would undoubtedly be a market for them. While Dr. A. J. Roux, vice-president of the South African Council for Scientific & Industrial Research and director of the Council's atomic energy research programme, is not so optimistic, he is of the opinion that South African industry cannot afford to wait before adapting itself for nuclear work. The engineering industry should be aided in its preparations to make nuclear power equipment.

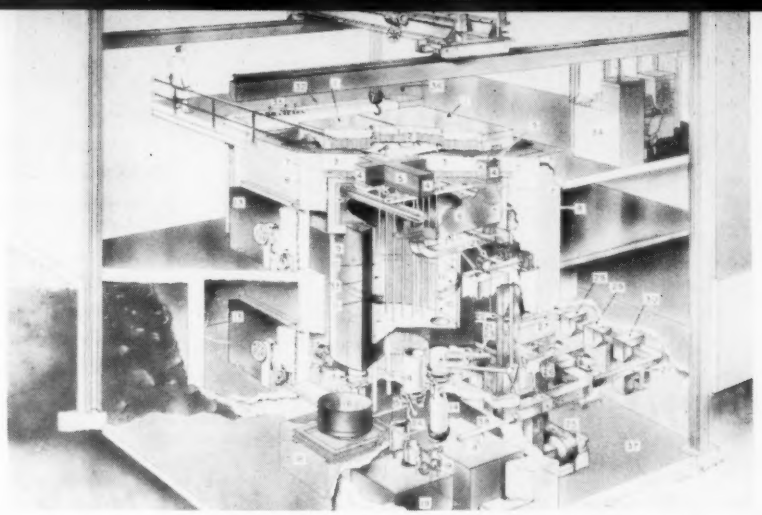
UNITED STATES

SS-clad fuels tested

During May an extensive gas-cooled loop system was put into operation by US General Electric in its 30 MW GETR reactor which recently reached its full power capacity. This equipment is being used to determine the behaviour of stainless steel clad uranium dioxide fuels under gas-cooled reactor conditions. Helium-filled loops will be employed and GE have manufactured many of the fuel assemblies to be irradiated and will be responsible for carrying out post-irradiation examinations.

AEC to have dual-purpose reactor

At an estimated cost of $M145 AEC issued contracts for the New Production Reactor at Hanford Works, Richland, Washington. This graphite-moderated reactor is to be used for the production of plutonium and special nuclear materials and a feature of its design is that it will be capable of conversion, if later required, to permit power take-off. The reactor design engineering is being carried out by the US General Electric and Kaiser Engineers of Oakland will be the principal constructors. It is envisaged that AEC would be able to sell its electricity output at 3·5 mills a kilowatt hour and at the same time produce plutonium at lower price than the present $30 per gram. Construction of the plant is anticipated to take some four years.



CANADA. As announced in Worldview last month, a new low-power (100 watts thermal) reactor, ZED-2, is to be built at Chalk River. Construction will be carried out by Foster Wheeler Ltd. Essential components are **1.** Top rolling shield; **2.** Reactor lid; **3.** Removable top shielding; **4.** Neutron shielding; **5.** Top shielding support beams; **6.** Header room; **7.** Fuel rod support lattice; **8.** Lattice support; **9.** Graphite reflector; **10.** Calandria; **11.** Control ring; **12.** Control ring drive mechanism; **13.** Concrete rolling doors; **14.** D_2O Fast dump pipes; **15.** D_2O Fast dump valves; **16.** Removable bottom reflector; **17.** Reflector dolly; **18.** D_2O Dump tanks; **19.** D_2O Pumps; **20.** D_2O Calandria supply pipe; **21.** Instrument still well; **22.** Freezer-drier supply duct; **23.** Freezer-drier return duct; **24.** Hydraulic hoist for removable reflector; **25.** Freezer-drier fan; **26.** Freezer-drier primary heater; **27.** Freezer-drier cooling circuit duct; **28.** Cooling coil 'A' (Water 70°F); **29.** Cooling coil 'B' (Freon 40°F); **30.** Cooling coil 'C' (Freon −30°F); **31.** Refrigeration condenser **32.** Fuel rod storage rack; **33.** Fuel rods; **34.** Control console; **35.** 12-ton bridge crane; **36.** Location for rod pickling, washing and drying tanks; **37.** Location for D_2O condensate recovery tanks, and **38.** Dump tank air vent line

Food irradiation proposals

Atomics International have proposed a design modification to the AEC of part of the Sodium Graphite Reactor being built at Hallam, Neb. By piping radioactive sodium, to provide source material, food irradiation could be carried out. The proposed facility would be equipped to process a wide variety of foods and would have an estimated capacity of 520 tons per day to provide limited preservation.

Radioisotope symposium

The AEC, in cooperation with Georgia Institute of Technology and Lockheed Aircraft Corporation, sponsored a two-day symposium on the Industrial Uses of Radioisotopes at Atlanta on May 11 and 12. This follows AEC's preliminary report on isotope applications which indicated that the US petroleum industry obtains most benefits, followed closely by the chemical and allied products industry. Feasibility of high radiation applications on a commercial scale, however, is still largely unrealized due, to a big extent, to the lack of suitable mechanisms for determining radiation changes in materials.

Tritium for civilian applications

AEC have now made 1M curies of tritium gas, at $2 per curie, available for industrial purposes and the Commission will consider supplying additional quantities on a continuing basis if required, until private sources of supply become available. The absence of penetrating radiation from tritium, the only radioactive isotope of hydrogen, is an important safety factor and this material is now being used in various marine and aerodrome markers and as lum nous instrument dials.

2-mile linac proposed

The United States President's science advisory committee has recommended that a new large electron linear accelerator is built. The project has been proposed by Standford University—it will be two miles long costing some $M100 and, it is anticipated, will take six years to build.

UZBEKISTAN

Nuclear research starts

At the recent annual meeting of the Uzbek Academy, it was announced that the Tashkent Institute of Nuclear Physics would soon be operating a reactor, a cyclotron and accelerators. To carry out a comprehensive research programme over the next seven years, the Academy's scientific staff is to be doubled and will eventually total 7500. Preparations have also begun on the establishing of a branch of the Academy in the Kara-kalpak Autonomous Republic, which is part of Uzbekistan.

Temperature effects and the presence of Xe-135 may lead to instabilities in a power reactor, which have a strong influence on the design of a suitable control system

Controlling instabilities in graphite power reactors

by J. G. TYROR, M.Sc.
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THE PRINCIPAL REQUIREMENTS of a control system of any power reactor are that it should be capable of ensuring the safety of the reactor and of bringing the reactor up to and maintaining the demanded power level. The safety and integrity of a reactor may always be ensured by having at all times sufficient negative reactivity available to shut the reactor down in a time small compared with the time scale of any possible reactor excursion. For power control purposes the design of a control system is strongly influenced by the dynamic response of the reactor to reactivity changes, and in order to design an adequate control system it is important to know just how a reactor will behave in a wide range of possible circumstances.

The changes that occur in a reactor, in the absence of controlling mechanisms, when it is disturbed from its normal steady state operating condition may take one of several forms, depending on the characteristics of the reactor and the nature of the disturbance, Thus, for example, the reactor neutron flux pattern may simply adopt a new equilibrium configuration, or it may oscillate or diverge, i.e. the disturbance will grow. For a reactor which diverges, the steady state is said to be unstable, and since perturbations are always present in a reactor system, an unstable reactor would diverge if not controlled. As we shall see, large graphite power reactors of the type currently being built for the UK Electricity Generating Boards fall into this category.

It is particularly useful to know the time scales on which changes in a reactor will take place. Thus, if a reactor diverges when disturbed from its steady state in the absence of control, it is of considerable value to know whether the doubling time of the excursion is of the order of a few minutes or several hours. Similarly, the nature of the control system and associated detection instrumentation will be influenced by any spatial peculiarities which may arise in the reactor's dynamical behaviour.

In this connexion it is possible to distinguish two types of instability:

1. A fundamental instability in which, if unchecked, the neutron flux, and hence power density, throughout the reactor would rise or fall in a uniform manner. This type of instability can be countered by adjusting the control anywhere in the reactor.

2. A spatial instability in which the size and magnitude of the divergence would be a function of position in the reactor. Thus, for example, the neutron flux might rise in one half and fall in the other half of the reactor. In this case it would be desirable to have a control system capable of adding or removing absorber at particular points. Uniform control would be inadequate since this would lead to local overheating even if the total power output were kept constant.

The basis of controlling the total power output has long been appreciated but the requirements for control of the actual flux shape in the reactor core have only become clear relatively recently (*1*, *2*, *3*).

In graphite-moderated, natural uranium power reactors there are two principal potential sources of instability. The first is the interaction between the temperature of various materials and pile reactivity. This effect is usually considered in terms of a temperature coefficient of reactivity, α, for the particular material. For positive values of α, an increase in material temperature results in an increase in pile reactivity which in turn leads to a further increase in temperature. On the other hand, a negative temperature coefficient is indicative of a stabilizing influence.

The presence of delayed fission product poisons is the other source of instability. The particular poison of interest is Xe-135, which combines a high yield with an enormous absorption cross-section for thermal neutrons.

Physical time constants

Before investigating these sources of instability in detail, it is instructive to consider the time scales on which

they may be expected to act. The basic time constant of the neutron flux distribution is associated with the mean neutron lifetime. For a graphite reactor this is about 70 ms. The time constants for temperature changes are on the whole much longer. The time constant for heat transfer from the uranium fuel is of the order of a few seconds, whilst for the graphite moderator the comparable figure, on account of the large thermal capacity, is many minutes. For the Xe-135 distribution the characteristic time is measured in hours, being associated with the decay constants of Xe and its precursor I-135.

$$\text{Fission} \rightarrow \text{I-135} \rightarrow \text{Xe-135} \rightarrow \text{Cs-135}$$

$$2\text{ min} \qquad \frac{1}{\lambda_I} = 6{\cdot}7\text{ h} \qquad \frac{1}{\lambda_X} = 9{\cdot}2\text{ h}$$

Events connected with the burnup of fuel are essentially long-term reactivity effects and have time constants so much greater than those discussed above that they can safely be ignored for day to day kinetic considerations.

In a power reactor, the steady state condition may be envisaged as being one of delicate balance between the various interacting quantities, such as neutron flux and xenon concentration. To obtain an accurate picture of reactor behaviour following a disturbance it is necessary to consider all these effects in some detail.

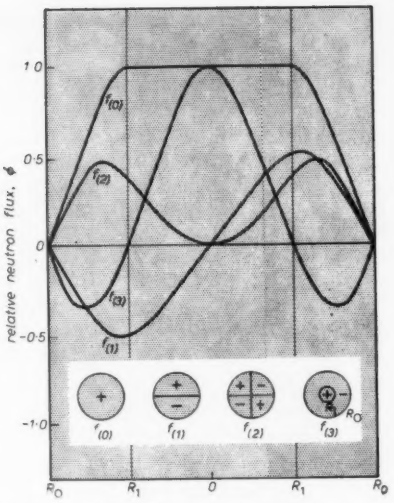
Temperature effects

In general we may write the effect of temperature change on reactivity in the form

$$k_\infty = k_\infty{}^* + \sum_i \alpha_i T_i{}^1$$

where k_∞ is the usual reproduction constant and T_i is the temperature of the ith reactor material. Here and throughout, an asterisk denotes a steady state value and a prime denotes a departure from steady state. In the Calder Hall type reactors, only the uranium fuel and graphite moderator are associated with significant temperature coefficients. The fuel coefficient α_u is due to the Doppler broadening of U-238 resonance absorption and has a value of about $-2.10^{-5}/°C$. The moderator coefficient α_g is very sensitive to the amount of Pu present in the fuel and, although negative at zero irradiation, is positive at high irradiations and may reach a value of $+15.10^{-5}/°C$ (*4*). The net temperature effect in this case would thus be destabilizing as soon as the deviation of graphite temperature from the steady state exceeded 2/15 of the fuel temperature deviation.

Initial temperature deviations will depend upon the nature of the disturbance, but in view of the relative promptness of the negative fuel effect it may be anticipated that for the first minute or so the response is stabilizing. After several minutes, when the moderator temperature is also affected, the temperature distributions may be pictured as passing through a series of quasi-steady states and the temperature deviations for the instabilities of most interest (see section on instability criterion) will be proportional to the steady state temperatures relative to coolant inlet temperature. These



Radial and, in the box, azimuthal flux distributions for (r,θ) modes in a flattened reactor with $R_1/R_0 = 0{\cdot}5$. Note that f_0 and f_2 modes are independent of azimuthal variation; f_1 is dependent on $\cos\theta$, f_2 on $\cos 2\theta$ (Fig. 1)

quantities T^* depend upon the heat removal from the core. For large values of T^*, heat removal is inefficient and changes in neutron flux have appreciable effect on the material temperature. The question of whether the temperature effects are stabilizing or destabilizing thus depends upon the sign of the quantity

$$\triangle k_T = \alpha_u T_u{}^* + \alpha_g T_g{}^*$$

where $T_u{}^*$ and $T_g{}^*$ are measured above coolant inlet temperature and are suitably averaged over the reactor core.

The temperature effect upon stability is clearly likely to be most marked in systems with poor heat removal characteristics (large T^*) and large temperature coefficients. In the current gas-cooled graphite reactors the amount of reactivity held in the temperature distribution may reach values of the order of $\triangle k_T = +15.10^{-3}$ at high irradiations.

Xenon effect

In a steady state reactor the distribution of Xe-135 assumes an equilibrium value where the rate of formation of the poison by the decay of I-135, with a delay of several hours, just compensates the loss of Xe-135 by decay and neutron absorption. The interdependence of the Xe-135 and neutron flux distributions in the equilibrium state leads to a destabilizing effect. For if, for some reason, the flux in a region of the reactor were to be increased slightly, this would lead to an increase in the rate of destruction of Xe-135. Due to the hold up in the iodine there would be no immediate compensating increase in the production rate of Xe-135. The net effect would be for the Xe-135 abundance in the region considered to decrease. Thus, since fewer poisonous absorptions could then take place, the neutron flux would increase still further.

Eventually, however, the increase in the production rate of Xe-135 would become effective. Provided that the initial departure from the steady state were not too severe, the production rate could, in fact, catch up with the rate of destruction of Xe-135. The motion would

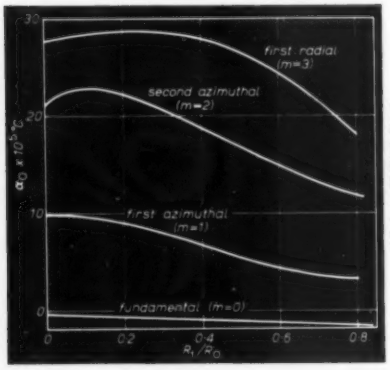
then be reversed. In these circumstances the behaviour is of an oscillatory nature. For reactors in which the xenon destabilizing effect is large the production rate can never catch up with the rate of destruction of Xe-135. In this case the departure from steady state is in a straightforward exponential manner.

The actual magnitude of the xenon effect ($\triangle k_X$) clearly depends upon the reactivity held by xenon in the steady state ($\triangle k_p$). This may amount to nearly 20.10^{-3} in the Calder type reactors.

Instability criterion

In order to decide whether a given reactor steady state is stable or not let us consider the introduction of an excess number of neutrons into a particular region of the reactor. If the net effect is for the neutron density (or flux) to increase, the steady state is unstable.

As we have seen, the effects on the xenon and temperature distributions are destabilizing, at least for large α_g. In considering the possible fates of the excess neutrons, however, it is clear that some will leak from the particular region affected and tend to reduce the density there. There is thus an important stabilizing factor present in the neutron diffusion process itself. It also follows that the effect is large when the regions involved are small, for then the flux gradients introduced, for a given excess of neutrons, are large. We may picture this essentially geometrical effect as introducing a negative reactivity change, $\triangle k_D$. The value of this term will depend upon the size of the region affected and the ability of neutrons to diffuse from it. In fact it may be shown that $\triangle k_D$ is proportional to the square of the neutron migration length, M, measured in units of a characteristic reactor dimension. Thus for a given reactor material the stabilizing term is largest for physically small systems.



Critical values of moderator temperature coefficient for instability. Here $M^2/R_0^2 = 1{\cdot}7.10^{-3}$, peak rating = 4 MW/tonne, $\alpha_u T_u^* = 5.10^{-3}$, $T_g^* = 150°C$ (Fig. 2)

The question of overall reactor stability then hinges on the three-cornered competition for the excess neutrons from absorption in xenon, diffusion, and absorption in fissionable material to produce temperature change, i.e. in the sign of

$$\triangle k = \triangle k_X + \triangle k_D + \triangle k_T$$

For $\triangle k = 0$ the reactor is said to be on the threshold of instability.

The value of the xenon term depends upon the rate at which xenon can be removed from the core. In fact it may be shown that as far as determining the stability threshold is concerned

$$\triangle k_X = \triangle k_p \frac{\phi^* \sigma_X}{\lambda + \lambda_X + \phi^* \sigma_X}$$

where $\phi^* \sigma_X$ is the forced decay constant of Xe-135 by neutron absorption. The term $\triangle k_X$ is always positive (and destabilizing), increases with increasing power rating and for natural uranium reactors saturates for very high fluxes at a value of about $+32.10^{-3}$. For graphite power reactors with a peak rating of 4 MW/tonne the appropriate value is $\triangle k_X = +5.10^{-3}$.

In order to obtain values for the diffusion term, $\triangle k_D$, it is useful to consider the harmonic analysis of flux perturbations. Now the spatial dependence of the steady state neutron flux in a large graphite reactor satisfies, to a good degree of approximation, an equation of the form

$$(\nabla^2 + B^2)\,\mathrm{f} = 0$$

This is an eigenvalue equation for which there are a set of functions f_m, with appropriate B_m^2, each of which satisfies the equation together with the appropriate boundary conditions (e.g. $\mathrm{f} \to 0$ at a given distance beyond core boundary). The steady state flux is proportional to f_0 the corresponding B_0^2 being the smallest of the eigenvalues. The higher harmonics are not present at equilibrium, but in general any perturbation to the steady state flux is expressible in terms of these eigenfunctions f_m. For a uniform bare cylindrical core

$$\mathrm{f}_m \equiv \mathrm{f}_{klm} = \mathrm{J}_n \left(\mathrm{j}^{(k)} \frac{r}{R_0} \right) \cos n\theta \, \sin \frac{l\pi z}{L_0}$$

where k, l and n take integer values, r, θ, z are the usual cylindrical coordinates, R_0 and L_0 are the extrapolated core radius and height and $\mathrm{j}_n^{(k)}$ is the kth zero of the Bessel Function J_n. Fine structure and reflector effects are neglected. The fundamental mode is given by

$$\mathrm{f}_0 \equiv \mathrm{f}_{110} = \mathrm{J}_0 \left(\mathrm{j}_0^{(1)} \frac{r}{R_0} \right) \sin \frac{\pi z}{L_0}$$

The higher modes can be conveniently divided into those with $l = 1$ (radial and azimuthal modes) and those with $l \geqslant 2$ (axial modes). In particular, the mode $\mathrm{f}_1 \equiv \mathrm{f}_{111}$ is frequently referred to as the first azimuthal mode. On account of the $\cos\theta$ term it is clearly positive on one side of a diametral plane and negative on the other. Similarly the second azimuthal mode $\mathrm{f}_2 \equiv \mathrm{f}_{112}$ has two nodal diametral planes. The first purely radial mode $\mathrm{f}_3 \equiv \mathrm{f}_{210}$ has differing signs within and without a region of fixed radius. In the CEGB-type reactors, with their flattened central zone, the harmonics are basically similar. The radial and azimuthal dependence of the f_0, f_1, f_2 and f_3 modes is illustrated in Figure 1 for the particular case in which the radius of the flattened region is half the total core radius. For larger values of k, l, n, the modes are rapidly varying functions which change sign over small regions of the core. As indicated earlier, perturbations of this type are associated with strong stabilizing characteristics. The excess neutron dif-

fusion introduced by the f_m mode is proportional to $(B_m^2-B_o^2)$ and the reactivity held in the actual shape of the mode is given by

$$\triangle k_D = -M^2(B_m^2-B_o^2)$$

In particular, for perturbations entering through the fundamental mode ($m = 0$), there is no change in the basic flux distribution and hence no stabilizing diffusion term. Values of $\triangle k_D$ for other modes of interest are given in Table I for the case where $M^2/R_o^2 = 1{\cdot}7.10^{-3}$

TABLE 1 *Values of* $\triangle k_D$

MODE	f_1	f_2	f_3
Unflattened core	15.10^{-3}	35.10^{-3}	42.10^{-3}
Flattened core ($R_1/R_o = 0{\cdot}5$)	10.10^{-3}	27.10^{-3}	41.10^{-3}

It will be noted that the modes have been labelled in order of increasing $\triangle k_D$ and that one effect of flattening the steady state distribution is to reduce the value of the stabilizing diffusion term.

It is convenient to express the instability criterion in terms of a condition on the moderator temperature coefficient α_g, i.e. $\alpha_g > \alpha_{go}$ for instability.

Values of α_{go} are given in Figure 2 for a graphite power reactor broadly similar to the type currently being built for the CEGB and SSEB. As irradiation (and α_g) increases, instability first enters through the fundamental mode. With increasing irradiation, instability enters through other (spatial) forms—firstly through the first azimuthal mode, then through the second azimuthal mode and so on. Bearing in mind that a value of $\alpha_g = +15.10^{-5}/°C$ may be reached at high irradiations, the steady state distribution would then be unstable to perturbations of both fundamental and higher harmonic form.

It may be anticipated that the doubling time associated with the fundamental mode instability would be less than the corresponding time constants of the spatial instabilities. Following a perturbation to an uncontrolled reactor, the fundamental mode instability would therefore predominate. If this mode were perfectly controlled, the reactor instability would be dominated by the first azimuthal mode and its associated time constant. This state of affairs might arise, for example, in a reactor in which the control of total power output was perfect, but the output from individual regions of the reactor fluctuated.

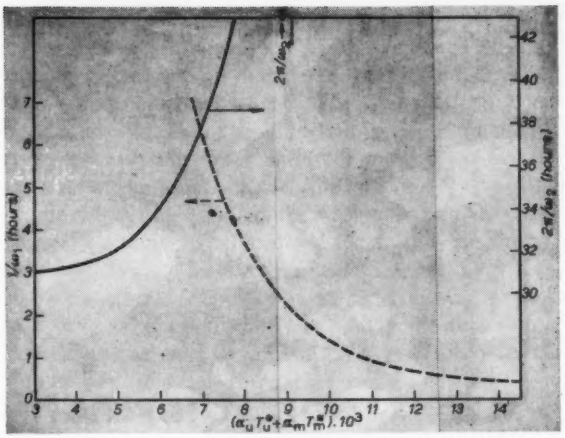
Thus in designing a control system for an unstable reactor it is necessary to bear in mind all the possible modes of instability in order to ensure continuous satisfactory operation.

Time constants of instability

Estimates of the time constants associated with the various reactor flux modes may be obtained by a simple perturbation method (*2*). The deviation in the neutron flux from its steady state value is written in the form

$$\phi' = Ae^{\omega t}$$

and a simple algebraic equation $h_m(\omega) = 0$ obtained for each ω associated with the f_m mode. Clearly the ω of interest is that with greatest real part ($\omega = \omega_m^{max}$). Other



Unstable time constants for first azimuthal mode. $M^2/R_o^2 = 1{\cdot}7.10^{-3}$, $R_1/R_o = 0{\cdot}5$, peak rating = 4 MW/tonne (Fig. 3)

solutions contribute to initial transient effects following the perturbation.

For the fundamental ($m = 0$) mode values of $1/\omega^{max}$ (in seconds) are given in Table 2 for the particular case where the stabilizing fuel temperature effect is prompt and the moderator effect has a delay constant of 10 minutes.

TABLE 2 *Fundamental mode time constants*

$\alpha_g T_g^*$	10.10^{-3}	20.10^{-3}	50.10^{-3}	100.10^{-3}
$\alpha_u T_u^* = -5.10^{-3}$	610	210	78	42
$\alpha_u T_u^* = 0$	67	47	29	20

The effect of the prompt stabilizing effect is seen to be marked. For a graphite power reactor, values of $\alpha_g T_g^* = 20.10^{-3}$ and $\alpha_u T_u^* = -5.10^{-3}$ would not be unreasonable, so that perturbation doubling times of the order of two or three minutes may be expected. In view of this short time, the change in the xenon concentration is small and the effect is not important. It should be emphasized that the doubling time is for the perturbation itself and not for the actual flux level and applies at a time sufficiently long after a disturbance so that transient effects, associated with lower values of ω, are insignificant. Thus, if in an uncontrolled reactor operating at a steady power of 500 MW, the power increased to 501 MW, it would increase to 502 MW in a time of the order of two or three minutes, and so on.

For higher harmonics, e.g. the f_1 mode, the steady state is not so far over the instability threshold and the value of $1/\omega^{max}$ is consequently larger. The corresponding importance of xenon introduces the possibility of the characteristic oscillatory behaviour so that in general we write the dominating time behaviour in the form

$$\phi^{1} = B \exp\omega_m^{max} t \cos \gamma_m t$$

Values of $1/\omega$, ^{max} and the oscillation period $2\pi/\gamma_1$ are plotted in Figure 3 for a particular case in which the fuel effect again is prompt and the moderator has a 10 minute time constant. In this example the reactor is unstable to a perturbation in the first azimuthal mode when

$$\triangle k_T > 3.10^{-3}$$

continued on p. 124

Britain's first open conference on this subject, held in London last month, showed that there has been a marked change of emphasis since Geneva

Zeta's original aluminium liner has been replaced by this 0·015 in. stainless steel bellows, which completely shields the torus from the discharge (Fig. 1)

Status report on thermonuclear research

by A. E. ROBSON, M.A., D.Phil.
C.T.R. Division, Harwell

RESEARCH INTO CONTROLLED FUSION is a subject which looks a long way into the future. Apart from its promise of a new source of usable energy, the investigation of the behaviour of matter at very high temperatures has important applications in other subjects, such as astrophysics and space research. Although enthusiasm runs high in this new and rapidly expanding field, the problems to be faced should not be underestimated. When all the cards went on the table at Geneva, it was clear that the difficulties are only just being fully appreciated, and the attractive prospect of a deuterium-fuelled world may still be quite a long way off.

At the end of last month, the Institution of Electrical Engineers organized a Convention on Thermonuclear Processes, the first open conference on the subject to be held in this country. As was to be expected, the discussions were directed mainly towards the electrical aspects of fusion research, but review papers were given on the basic physics of hot plasma, and on the present state of research in Great Britain, USA and Russia. From these it was clear that there has been a marked change of emphasis since Geneva. Sir George Thomson, one of the originators of thermonuclear research in this country, said that he felt the 'heroic era' of CTR was now over; hitherto the approach had been to build machines which put a great deal of energy into a small quantity of deuterium, and to see what happened; each stage of the work seems to have revealed as many problems as it has solved, and the feeling is now that the next step must be to consolidate our knowledge and understand what is going on in present experimental devices before we can contemplate building a thermonuclear reactor.

The basic aims of thermonuclear research have been frequently described. A plasma of deuterium, or deuterium-tritium mixture, must be raised to a temperature at which the nuclear fusion reactions release more energy than is needed to maintain the temperature of the fuel, and the plasma must then be held at sufficient density and for long enough to pay back the energy used in heating the fuel charge. This, the so-called break-even point, requires a temperature of at least 40 million degrees for a D-T mixture, and an appreciably higher temperature for pure deuterium. Furthermore it is essential that heat losses from the plasma be reduced to the bare minimum, that is, that conduction and convection losses shall be made less than the unavoidable radiation loss (*Bremsstrahlung*) from the plasma electrons.

Containing the plasma

Magnetic fields seem to offer the only practicable way of containing a hot plasma. Their effectiveness in confining single particles is well established; the particles perform tight circular orbits about the lines of force, and can only move across the field as a result of mutual collisions, which at high temperatures should be sufficiently rare to keep the diffusion across the field tolerably small. A system of closed lines of force should therefore form an effective magnetic bottle in which plasma can be confined for long enough for many of the nuclei to react. This, at least, is the simple picture. When a large number of particles is confined in this way, several mechanisms arise through which the drift of particles across the field is drastically increased. The first of these to be encountered were the hydromagnetic instabilities, so called because their analysis involves regarding the plasma as an electrically conducting fluid in a magnetic field. More recently it has been realized that there may be also 'electrostatic instabilities,' or randomly fluctuating electric fields in an apparently stable plasma which can lead to enhanced diffusion across the magnetic field. To understand these instabilities is the most essential and immediate task in fusion research, since unless they can be overcome the heat loss from a magnetically confined plasma will be prohibitively high. In this connexion, an important parameter is the ratio of the plasma pressure to the magnetic field pressure, known as the β-value. In general, the

higher the β-value, up to its maximum possible value of one, the more likely the plasma will be unstable. This is unfortunate, because to set up magnetic fields requires the expenditure of electrical energy and to make the most effective use of the field for confinement, the β-value should be as large as possible.

Experiments in magnetic confinement of plasma are following three main lines: the pinched discharges, the stellarators and the mirror machines. In the last two the confining fields are produced by currents in external coils, while the pinch devices depend primarily on the field produced by a large current flowing through the plasma itself. The pinch has the advantage that the experimental arrangement is fairly simple, but since the current performs the dual function of heating and confinement, the processes occurring in the plasma are closely interdependent and therefore difficult to interpret.

In the simple pinch, the current channel contracts until the plasma pressure balances the magnetic pressure, so that $\beta \simeq 1$ and violent instabilities are encountered. These held up progress for a long time, but in defence of the pinch approach it should be pointed out that it has reached high β-values from the beginning, whereas the other approaches in general work at much lower values of β and perhaps for this reason have not encountered such dire instability troubles. At least, not yet.

Modifications to Zeta

The UK thermonuclear programme has concentrated mainly on the pinch effect and much of the convention was concerned with Zeta. The Geneva paper on its design and performance was re-presented, and supporting papers on the detailed design of its transformer vacuum system and switchgear were given by representatives of Metropolitan-Vickers, who built the machine. Much of this was however ancient history, and greater interest was attached to papers describing the modifications to Zeta during 1958, and the engineering problems which are anticipated in more advanced Zeta-type systems.

The main modification to Zeta has been the replacement of the liner inside the torus. This liner is necessary to prevent electrical breakdown of the two main insulated gaps in the torus body, and originally consisted of a series of 48 water-cooled aluminium sections, overlapping and insulated from each other. It turned out in practice that aluminium was not a very suitable material and was badly damaged by the discharge; the plasma was heavily contaminated and frequent short-circuits occurred between the liner sections which meant that the liner system had to be completely dismantled for overhaul. Work carried out on the behaviour of materials when bombarded by plasma showed that stainless steel was the best choice of the more common materials, and the new liner system consists of a continuous stainless steel bellows, 0·015 in. thick, which completely shields the torus from the discharge (Figure 1). It forms an electrical closed circuit, but its resistance is sufficiently high to limit the current in it to about 100 kA compared to the inductively-limited 300 kA in the plasma.

The other significant modification has been to transfer the primary winding from its former position on the iron core of the transformer to the outside of the torus; this improves the coupling between the primary and secondary circuits. The modified Zeta, now known as Zeta 1A, has so far proved more reliable than the aluminium-linered Zeta 1, but no remarkable new results have been obtained from it. The emphasis has been to put the machine on a reliably-engineered basis, so that consistent measurements can be made on a somewhat cleaner plasma.

Results were also described from the smaller toroidal discharge machine, Sceptre III, at the AEI Research Laboratory. This has also undergone modification since Geneva, mainly to increase the stabilizing magnetic field and to provide improved facilities for making measurements on the discharge.

The results which have been obtained with Zeta, Sceptre and the much smaller Perhapsatron S4 at Los Alamos, are basically similar if suitable scaling laws are applied to correct for their widely different sizes. The advantage of larger machines is in their longer time scale, milliseconds instead of microseconds, which makes measurements on them easier, and also in the reduced heat-loading on the walls, which simplifies the materials problem. Against this must be set the practical disadvantage that it takes longer for modifications to be made on a large machine.

Stabilizing the pinch

The first step towards stabilizing the wriggling pinched discharge was the application of an axial magnetic field; this appears to stabilize the current channel against the worst types of instability, but smaller-scale fluctuations remain. The measured ion temperatures are of the order 5.10^6 °K, while the electron temperatures are of the order 5.10^5 °K, a discrepancy for which a variety of explanations has been offered but which has not been quantitatively explained. In view of the enormous power instantaneously being supplied to a very small mass of gas (the peak power in the Perhapsatron is about 900 MW) the plasma temperature is disappointingly low, which shows that heat losses are occurring which are much greater than expected on the basis of the diffusion of a quiescent plasma across the magnetic field. These losses may be due to intense radiation from the impurities in the plasma, but a more likely cause seems to be hydromagnetic or electrostatic instabilities of a somewhat more subtle nature than the gross wriggling of the early pinched discharges.

Theories of stability have always kept one step ahead of their experimental verification, but on the currently-accepted theory the discharges in Zeta and Sceptre

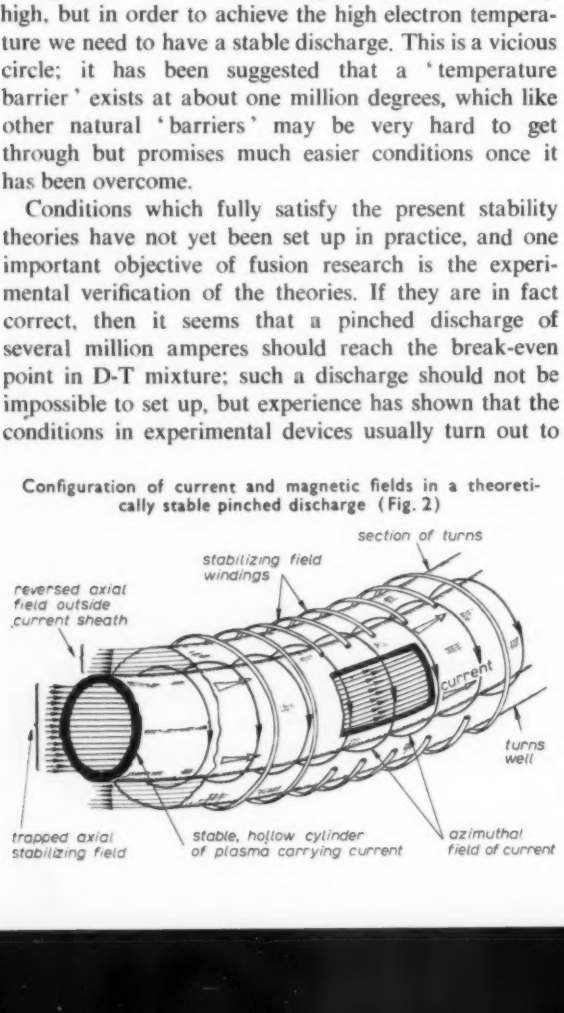
would not be completely stable. To produce a completely stable pinch would seem to call for a rigorous configuration of currents and magnetic fields. The current must flow in a hollow cylinder which encloses an axial magnetic field; outside the current channel there should be an azimuthal component of magnetic field due to the current, and also an external axial field component in the opposite direction to the internal axial field.

To set up such a configuration in practice calls for a great deal of experimental ingenuity, since it involves the rapid switching of currents from thousands to hundreds of thousands of amperes. The best method seems to be to apply first an axial field to the discharge tube, and then to establish the main current very rapidly (Figure 2). By the familiar 'skin effect' the current begins to flow in a sheath close to the wall, which then contracts towards the axis, compressing the axial field inside it. The external axial field can then be reversed by changing the direction of the current in the stabilizing field coils.

The possibility of separating magnetic fields in this way depends on the plasma having a high electrical conductivity; this increases with temperature and at 10^7 °K would be ten times that of pure copper, so that most stability theories in fact regard the plasma as a superconductor. In practice the finite conductivity means that the initial configuration cannot be held indefinitely, because the fields will diffuse through the plasma shell and the stability criteria will be violated. It seems therefore that in order to produce a stable configuration the electron temperature must be very high, but in order to achieve the high electron temperature we need to have a stable discharge. This is a vicious circle; it has been suggested that a 'temperature barrier' exists at about one million degrees, which like other natural 'barriers' may be very hard to get through but promises much easier conditions once it has been overcome.

Conditions which fully satisfy the present stability theories have not yet been set up in practice, and one important objective of fusion research is the experimental verification of the theories. If they are in fact correct, then it seems that a pinched discharge of several million amperes should reach the break-even point in D-T mixture; such a discharge should not be impossible to set up, but experience has shown that the conditions in experimental devices usually turn out to be far more complicated than the theories assume, so optimism should be restrained until the experiment has actually been performed.

Configuration of current and magnetic fields in a theoretically stable pinched discharge (Fig. 2)



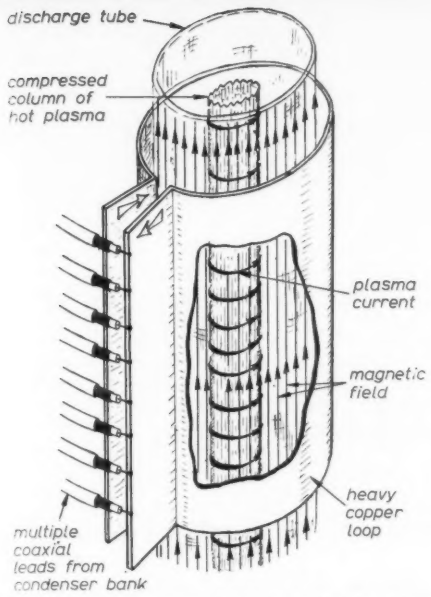
The Convention included papers on the technical problems of producing high-current discharges and their associated stabilizing magnetic fields. To achieve the required high instantaneous power input, pulse techniques are invariably necessary in which energy is rapidly transferred from an energy store into the apparatus. The energy store can be a condenser bank, an inductance, a storage battery or a rotating machine, the choice in any particular experiment being dictated by the rate at which it is required to release the energy. The condenser bank offers the fastest rate of discharge, but is bulky and expensive. The rotating machine stores energy efficiently and compactly, but can only deliver it slowly. The inductive energy store comes somewhere in between. Up to the present condenser banks have been widely used and the time scale of the experiments has been relatively short. An attractive possibility seems to be to establish a discharge rapidly by means of a 'fast' condenser bank and then to prolong its duration by the slower discharge of an inductive energy store. This method offers economic advantages over a very large condenser bank when energy storage of hundreds of megajoules is contemplated. The present Zeta condenser bank stores only half a megajoule.

Fast condenser techniques

It is becoming increasingly clear that the configurations needed for stability will have to be set up very rapidly—in a matter of microseconds—if they are to be achieved at all. This in turn means that the initial rate of current rise will be high, with the additional possibility that shock waves in the collapsing current sheath will contribute to the heating of the plasma. Work on high-current discharges in which the current rises at a rate of $2{\cdot}10^{12}$ amp/s has been going on at AWRE with their straight discharges Maggi and Minni, and it is felt that rates of rise up to a thousand times faster are technically possible.

Fast condenser techniques are also used in another device reported from AWRE. Known as the Thetatron, this machine heats and compresses plasma by means of a rapidly rising external magnetic field. The condenser bank is discharged into a single copper loop surrounding the discharge tube; azimuthal currents are induced which interact with the magnetic field to compress the plasma towards the axis. The resulting configuration (Figure 3) differs from the pinched discharge, in that the directions of current flow and magnetic field are interchanged, and preliminary results seem to indicate that it is more stable than the pinch. Similar results have been obtained in the USA with a device called Scylla, but both are still in an early stage of development.

A review of the work going on in the USA was



AWRE's Thetatron, shown here in principle, heats and compresses plasma by means of a rapidly rising external field (Fig. 3)

given by Dr. Chester van Atta of UCRL. The scale and diversity of the American Sherwood Project is most impressive, but they too have come up against difficulties of a fundamental nature. Both the stellarators at Princeton and the pinch machines at Livermore and Los Alamos suffer from severe heat losses which appear to limit the electron temperature to less than a million degrees. The emphasis in the American work has therefore also shifted towards understanding of the fundamental plasma processes as an essential step which must come before a power reactor can be designed. Many small-scale experiments are in progress to investigate the energy loss mechanism.

Mirror machines promising

The change of emphasis is reflected by the change of attitude towards the neutrons which are now emitted from practically all the pinched discharges in deuterium. These caused great interest when they first appeared but their origin is still not understood. It is clear that they are not due solely to the temperatures achieved, and their importance has fallen to just another piece of evidence that many complicated processes are at work inside a plasma. The largest number of neutrons, 10^9 per pulse, comes from an unstabilized straight pinch, and it will not be until yields of the order 10^{12} per pulse are obtained that their 'thermo-nuclearity' will be beyond doubt.

While the pinch approach is being plagued by instability trouble, work on mirror machines is of particular interest since these have so far shown no apparent instabilities. Whether this is due to some fortunate property of the magnetic mirror configuration or to their relatively early stage of development is not yet clear, but temperatures of more than 10^7 °K at β-values of 8% are claimed for one of the compression mirror machines at Livermore, although the volume of compressed plasma is very small.

The principle of the injection mirror machine, as typified by the DCX at Oak Ridge, is to form a plasma by randomizing and trapping a beam of fast ions in a steady magnetic mirror field. By giving the ions the necessary high energy by direct acceleration, this machine stands a good chance of avoiding the temperature barrier altogether. It has however encountered a barrier of its own. At present the fast ions are trapped by injecting them as molecular ions and breaking them up into atomic ions by the action of a powerful arc inside the machine. The atomic ions should then be confined by the field for long periods, but instead they are rapidly lost as a result of charge-exchange collisions with the residual gas atoms, which turn them into fast neutral particles uninfluenced by the magnetic field. To overcome this effect, the ions must be injected at a greater rate than they are lost, a condition which is known as burnout, but has not yet been achieved.

The largest injection mirror machine yet built is the Ogra, at the Moscow Institute of Atomic Energy. Its inventor, Dr. Igor Golovin, was among the Russian delegation to the Convention and gave an account of the progress made to date. With a vacuum chamber 4·5 ft in diameter and 39 ft long, this machine used collisions with residual gas atoms to achieve breakup of the molecular ion beam, and its great size is a consequence of this trapping method. The main features of the Ogra were described at Geneva, when it was still under construction, but now a vacuum of 3.10^{-8} mm Hg has been created in the chamber, and a beam of 30 mA of hydrogen ions at 100 keV has been injected. Burnout has not been achieved, and is not expected until the injected current and energy are increased, and it was emphasized that the machine is still in the alignment stage. However, Dr. Golovin seemed optimistic, but pointed out that the problems being faced by mirror machines are at present technical ones, and the real test of their feasibility as reactors will not come until it has been shown that stable plasma at large β-values can be confined in them.

Proposal for direct conversion

Looking a long way ahead, the possibility of direct conversion of thermonuclear energy into plasma energy is of great interest. One proposal which might be used in a pinched discharge reactor is to modulate the current so that the pinched plasma undergoes a compression-reaction-expansion cycle in which a net amount of work is done against the confining magnetic field. This work would appear as electrical energy in the main discharge circuit. Only the energy of the charged reaction products could be harnessed in this way; the energy which is carried by the neutrons must inevitably be converted via a thermal cycle, so that at best no more than 30% of the available energy could be withdrawn directly. A reactor using this principle would require squarely-modulated currents of about 8 MA in D-T and about 70 MA in D-D.

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Scotland's first nuclear power station

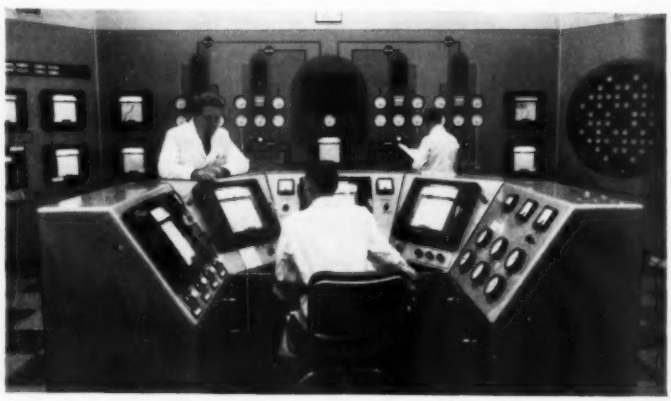
CHAPELCROSS

officially opened on May 2, 1959, by

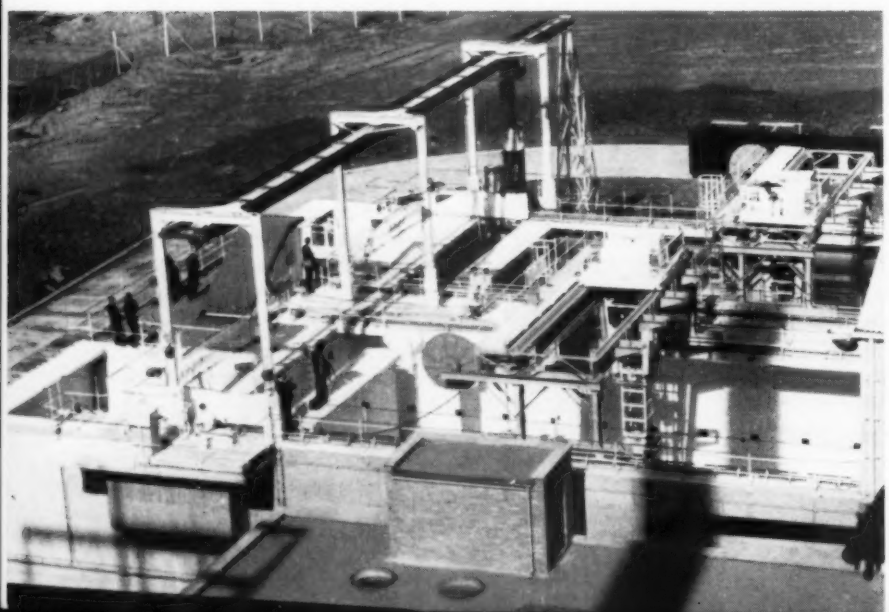
Sir John Crabbe, O.B.E., M.C., T.D.

H.M. Lord Lieutenant for Dumfriesshire

CONTRACTORS' DIFFICULTIES. To ensure a sound foundation for the biological shield of the No. 4 reactor, it was necessary to excavate to a depth of over 60 ft before sandstone rock was reached. Concrete structures, 90 ft high with 7 ft thick walls and 46 ft across the inside, were built directly onto the rock—the raft type foundations used at Calder Hall were not suitable for the type of ground at Chapelcross



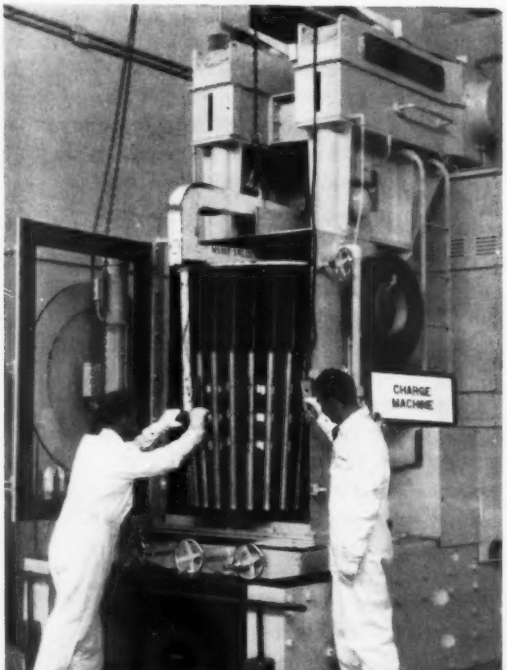
No. 1 REACTOR CONTROL ROOM. On the left—recorders for burst slug detection, temperatures and pressures. The centre wall is occupied by temperature and pressure indicators for the four heat exchangers and visual warning panels for reactor faults. On the right—control rod position indicators, showing the penetration depth of each rod. Also on this wall but not visible in the picture, are banks of 'fail safe' trips. The console holds the reactor power indicators and recorders, with the coarse and fine control rods operating controls



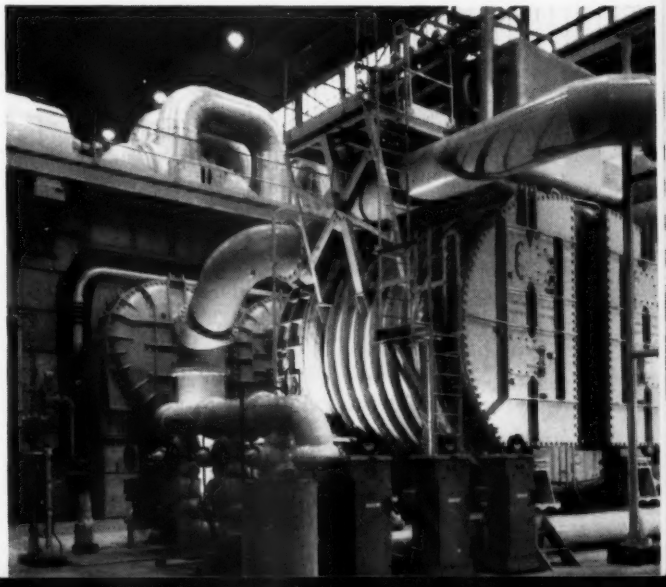
THE STORAGE POND. This is a feature not provided at Calder Hall and its main function is to ensure that transport delays do not affect the reactor outage time. The capacity of the pond is sufficient to hold cartridges equivalent to about three reactor charges. It is a reinforced concrete structure, consisting of two rectangular pools, joined side-by-side by a common wall. Each pool holds some 400,000 gallons of water, 18 ft deep. Standard containers holding 24 cartridges are used to take the irradiated fuel to the pond, where it is left to decay for some months before being transported by road to the plutonium processing plant at Windscale. Complete handling equipment and overhead cranes are incorporated. All the water is subjected to extensive filtering before it is released into the outflow

Overlooking the Solway Firth from high ground to the north, Chapelcross is virtually a duplicate of Calder Hall. The layout, however, differs essentially from that at Calder Hall in that the four reactors were built concurrently, the resulting arrangement is more efficient and a single large turbine house with four adjacent cooling towers, is used. Another feature is that the main steam lines and other service lines are located, generally, just below ground level in open trenches and are not carried overhead as at Calder Hall. When all four reactors are in full production, some 140 MW of electricity will be supplied to the South of Scotland Electricity Board. To prevent any possible radiation hazards growing up in the locality, an extensive planned sampling procedure has been initiated which will check at frequent regular intervals, milk, vegetation, the sea shore and gamma radiation at ground level, over a wide area around Chapelcross

LOADING A FUEL BASKET. Twenty-four fuel elements, sufficient for four channels, in a circular rotating basket are loaded into a charge machine. These machines are electrically propelled and carry a unit for raising and lowering the elements, one at a time, by means of an electrically operated grab. A wide range of controlled speeds, from 175 f.p.m. down to creep speeds is provided and the hoist cable carries the electrical cores for grab operation and remote indication



DUMP CONDENSERS. To prevent contaminated steam passing to the turbines in the event of a failure in the heat exchangers; to use any steam in excess of normal load requirements; and to cover for the possibility of the station being suddenly disconnected from the grid when on load, steam dump condensers are provided. Each is capable of taking the whole quantity of steam diverted from two loaded turbines. Primary desuperheaters using mechanically and thermostatically controlled spray nozzles reduce the temperature to about 300°F. Secondary desuperheaters fitted in the top chamber of the condenser reduce the temperature of the steam from 300°F to saturation point



With the experience gained at Calder Hall, the first of the four reactors of its almost identical copy was put into operation with greatly improved speed and efficiency

CHAPELCROSS :

Commissioning the first reactor

by D. R. R. FAIR, O.B.E., B.Sc., A.Inst.P.
Works Manager, Chapelcross Works, UKAEA

THE MAIN PURPOSE of the Chapelcross works is the production of plutonium, but when fully operational there will also be an electrical output of 140 MW into the South of Scotland Electricity Board's system. Situated some three miles from the Royal Burgh of Annan in Dumfriesshire, Scotland, the works were designed to be a copy of Calder Hall with only those modifications required by the site. Merz and McLellan were appointed as consulting engineers for the power plant layout, services and civil engineering and as construction agents for the whole station *(1)*. The station was planned for four reactors from the beginning and thus enjoys an improved layout compared with Calder Hall. The four reactors are in line with four cooling towers in a parallel line on one side and the turbine hall housing the eight turboalternators on the other. Preliminary work on the site began in July 1955 and reactor no. 1 was completed and ready for its pre-hand-over tests by July 1958.

TRAINING OF PERSONNEL

The majority of the staff and practically all of the workpeople were recruited specially for Chapelcross and were inexperienced in reactor operation. Consequently a training programme for each member of staff was drawn up and it involved both formal training and training on the job. The formal training was carried out at the Harwell Reactor School, the Royal Technical College, Salford, and the Calder Operations School. Training on the job was done at Calder Hall, SSEB's power stations at Dalmarnock and Braehead, and the Windscale works.

The Harwell Reactor School, and to a lesser extent, the Salford Royal Technical College course, gives three things to the newcomer to the industry: it provides a course in basic nuclear physics, a course in reactor physics and reactor control, and a wide general background of work in the radioactive, metallurgical and heat transfer fields. The Calder Operations School *(2)* course was of especial value to plant operators and particular attention was paid to the use of the Calder reactor simulator. Each operator had to perform a full approach to power and shut down from power on the simulator, observing all the reactor limitations that apply on the plant itself. The charts indicating the correctness of temperature and power control were assessed for each individual and a pass standard had to be achieved. There can be no doubt of the value to the Chapelcross staff of the courses at Harwell, Salford and Calder Hall.

Perhaps it is appropriate to mention that a number of staff, some with reactor experience, had not had a very wide power station experience and in this matter the SSEB were most helpful in permitting AEA staff to attend for periods of upwards of a month at their power stations. The training on the job included, for certain members of staff, working as part of the operating team at Calder Hall which was clearly of considerable value. The reactor and cartridge cooling pond process workers in radioactive working techniques were sent to train for six to eight-week periods on the cartridge cooling ponds at the Windscale Works.

Extensive use of plant manuals

The other aspect of preparation for commissioning upon which most effort was expended was the preparation of plant manuals. They were based upon the operational procedures in use at Calder Hall and fell into three groups :

1. Descriptive manual, in which a full technical description of the plant was given together with plant characteristics, dimensions and drawings
2. Plant operating instructions in which detailed instructions were given for bringing the whole plant to power, shutting it down and carrying out certain other standard operations. This section of the manual did not give instructions in the manner of operating individual items of plant.
3. Plant item operating instructions in which full instructions were issued for the operation of each item of plant. They included instructions on starting up,

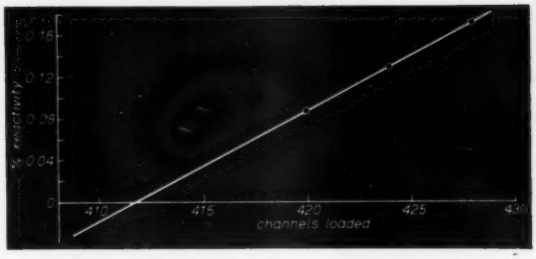
shutting down, attention whilst running normally, and emergency instructions for each piece of plant.

The effort expended in the preparation of these manuals, although considerable, was more than repaid by the amount of detailed information the operators learned about their plant whilst preparing them.

The works technical section were fully responsible for the preparation of the detailed commissioning programme and for the carrying out of the physics measurements associated with them. The programmes were issued well ahead of the time when each operation was to be carried out and consisted of three types of document:

1. A programme document which laid down responsibility for each item of work and the date and time when it was to be executed
2. A preparation document (e.g. 'Preparations for calibrating the control rods') which recorded in a series of schedules the exact state to which the whole plant was to be brought before the next operation began
3. An instruction document (e.g. 'Instructions for calibrating the control rods') in which the reason for or theory behind the work was simply stated and full details of the operations to be carried out given.

Special training in reactor calculations, foil counting, and other techniques necessary for the reactor physics measurements was arranged for members of the technical section of the Chapelcross operations team. In the weeks immediately preceding takeover, several briefing sessions were held when members of the Technical Section outlined to the Operations and Maintenance staffs the measurements to be made and the supporting theory.



Loading successively 420, 424 and 428 channels in the reactor and measuring the effect on reactivity, extrapolation back to critical size gave 411·8 channels, compared with the 411·6 estimated (Fig. 1)

COMMISSIONING THE PLANT

During the construction of the plant and prior to the plant proving trials, many tests, both at contractors' works and on site, were carried out. Some of the more important *(3)* were:

1. Reactor vessel—pneumatically pressure tested following electrical stress relief of the whole shell
2. Heat exchangers—hydraulically pressure tested before raising to the vertical
3. Main and auxiliary circulators—tested in a closed loop on site to prove gas tightness and effectiveness of stationary and running seals
4. Control rod mechanisms—tested in a test rig on site before installation in the vessel.

A detailed test schedule had been drawn up in the design office for each piece of equipment associated with the reactor and the plant proving trials were

STATION DATA

CAPACITY
46 MW from two turbines fed by four heat exchangers
Heat rating: 180 MW
Complete station includes four reactors and 8 turboalternators
Maximum electrical output: 184 MW
FUEL
Natural uranium cast bars, 1·15 in. dia, 40 in. long
Vertical channels, six elements per channel
Total number of channels: 1696
Total investment: 130 tonnes
CANNING
Magnox; wall thickness 0·072 in.
Extended surface: single-start helical fin, 0·125 in. pitch, 0·43 in. radial width, overall dia, 2·125 in.
Manufacture: cans turned from solid, swaged on to uranium, helium filled.
MODERATOR
Graphite; 8 in. sq. interlocking blocks and tiles
Drilled 4 in. (av.) holes for fuel channels
Overall size, including reflectors, 36 ft dia, 27 ft high
Supported by ball bearings on 4 in. plates resting on diagrid
Total weight: 1140 tonnes
CORE
Size 31 ft dia, 21 ft high
Lattice: regular square, 8 in. pitch
COOLANT
Carbon dioxide at 100 lb/in.² circulating upwards
Flow: 7·1 million lb/h
Ducting: 4 ft 6 in. dia
Inlet temperature: 140°C
Outlet temperature: 336°C
Shielding cooling: blown air
PUMPING
Four centrifugal blowers, one in each heat exchanger circuit
Total power absorbed: 5·44 MW
Speed control = Ward-Leonard type, range 10/1
CONTROL
Coarse: up to 48 rods ganged together
Fine: up to four, manually operated
Normal operation: total of 48 rods
Rod construction: boron steel in stainless steel tubes
Suspension: stainless steel cable
Travel: 21 ft
Maximum rod speed for shut off: 4 ft/s
Minimum automatic rod speed: 0·5 in./min
SHIELDING
6 in. steel plates
Concrete: on sides 7 ft, on top 8 ft
Minimum density: 150 lb/ft³, mean: 160 lb/ft³
Overall size: octagon 60 ft across flats, 90 ft high
Total weight on foundations: 32,000 tons

REACTOR PRESSURE VESSEL

DESIGN
Plate: 2 in. thick, ductile mild steel, 'Lowtem'
Vertical cylinder 37 ft inside dia and 71 ft 6 in. high with domed ends of ellipsoidal form; lower end has auxiliary dome 12 ft dia
Ten 'A' frame supports
Diagrid to support reactor core, weight 63 tons
MANUFACTURE
Prefabricated on site in five sections, bottom dome, two centre sections, diagrid and top dome
Vessel sections lifted into position in reactor biological shield

HEAT EXCHANGER

TYPE
Duel-pressure cycle
GAS CIRCUIT
Temperatures: 638°F and 285°F
STEAM
H.P. 195 lb/in.² and l.p. 48 lb/in.²
77% of power generated at high pressure
MANUFACTURE
Each dispatched to site in ten sections, comprising six sections of the shell, two domed ends and two halves of the base. Overall size of shell: 80 ft by 18 ft dia. Weight 178 tons. Total weight with equipment 450 tons

TURBOALTERNATOR

TURBINE
3000 rev/min, single flow, 15 stage h.p. cylinder coupled in tandem to a double flow l.p. cylinder
Steam conditions: 185 lb/in² (200 abs.) and 590°F for the h.p. unit, and 38 lb/in.² (53 abs.) and 340°F for the l.p. unit
ALTERNATOR
3000 rev/min 23 MW, at 11,000 V

DUMP CONDENSER

CAPACITY
514,600 lb/h (= 2 turbines = 4 heat exchangers = 1 reactor)
DESUPERHEATERS
Primary reduces steam temperature to approximately 300°F
Secondary reduces the temperature to saturation

COOLING TOWER

CAPACITY
3,000,000 gal/h from 87°F to 70°F
SIZE
290 ft high, throat dia. 104 ft and ring beam dia 200 ft

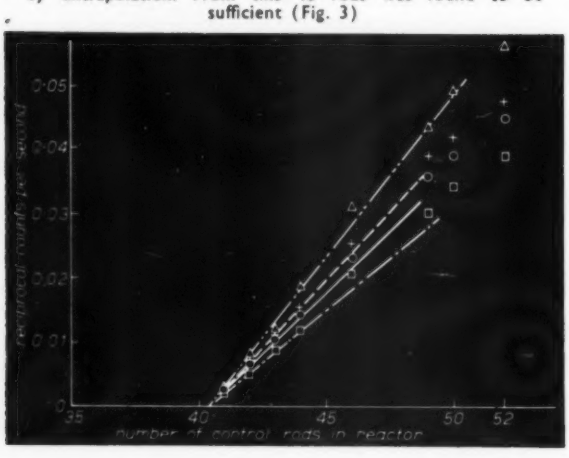
On the pile cap are the control rod actuators, painted dark blue, and the lighter flux scanners and thermocouples (Fig. 2)

carried out during the final stages of construction before the plant was handed over for operational commissioning. The tests were supervised by the consulting engineers and were observed by representatives of the design office and operating team as necessary. Complete trials were carried out on all major equipment under as far as possible final operational conditions and were in five main stages *(3)*:

1. Cold static pressure tests at 115 lb/in.²(g) using dried air
2. Cold dynamic tests at pressures up to 100 lb/in²(g). The dynamic tests at atmospheric pressure included runs with full flow filters inserted in each gas circuit and a test to observe mechanical stability during which men were stationed in the vessel whilst the blowers were run at full speed
3. Hot dynamic pressure tests at 115 lb/in²(g), 140°C, during which tests were carried out on the main gas circulators, the Ward Leonard sets, ancillary equipment such as cyclones and circuit driers the control equipment and instrumentation. The safety circuits and gas sampling equipment were also tested
4. Trials of the fuel element charge and discharge equipment
5. Functional test of the carbon dioxide plant.

Some of the equipment, similar in design to that at Calder Hall, had been modified on the basis of experience at Calder Hall. The testing was required to show that the equipment was mechanically sound and also to provide in certain cases experience for the plant operators. The tests were concluded satisfactorily to programme and the plant was formally handed over to the operating department on November 3, 1958.

Taking measurements on four ion counters in the thermal column, the number of the 52 control rods originally installed which had to be withdrawn for criticality was found by extrapolation. From this 48 rods was found to be sufficient (Fig. 3)



REACTOR COMMISSIONING

1. Loading to criticality

After hand-over to the operations team and before uranium was loaded into the core three days of preparation work were needed for:

1. Installation of scaffolding in the sub-diagrid area of the vessel so that inspection of channels, both loaded and unloaded, could be carried out
2. Installation in the vessel of lighting and a removable charge pan identification system, because much of the work in the first six weeks after hand over called for men to be inside the vessel
3. Installation of a motorized drive to the fine control rod withdrawal mechanism and a fast rate of withdrawal added to the coarse control rod withdrawal mechanism so that a rapid approach to criticality could be made during the early physics measurements. These modifications were removed as soon as the reactor was loaded to have 0·2% of reactivity
4. Installation of a temporary telephone system linking together the reactor control room, the sub-diagrid, the vessel interior at charge pan level, the temporary change room in the envelope leading to the 54 in. duct through which entry to the vessel is effected, and the reactor cap
5. Final control rod dropping tests to ensure that the time of fall from fully out to the application of full braking was within specification, also for the testing of every safety circuit
6. Inspection of the vessel and the gas circuit and the setting and locking off where appropriate of valves according to the start up schedule.

Loading of uranium into the core began at 02.55 hours on November 6, 1958. The fuel elements were loaded by machines from the reactor cap to the charge pan level through two selected charge tubes near the edge of the core. The cartridges were removed from the grab at charge pan level and were loaded by hand into the channels at the centre of the core maintaining cylindrical symmetry. The approach to critical size was observed by making a neutron count in the top reflector when all of the control rods were withdrawn. It was clear quite early in the operation that the critical size would be in close agreement with that for Calder reactor no. 3 i.e. 412 channels. Therefore measurements were made at six stages only prior to going critical, i.e. at 64, 192, 240, 300, 360 and 400 channels loaded. This may be compared with the approach to critical in Calder reactor no. 1 *(4)* when it was deemed prudent to approach critical size in steps of four channels at a time.

When the critical size was accurately estimated the reactor was made slightly supercritical and the protection circuits were tested. Criticality was established by loading 416 channels and on withdrawing the control rods the reactor diverged for the first time at 16.20 hours on November 9, 1958, with a doubling time of approximately 120 seconds and was shut down by the operation of the reactor protection equipment which had been set to operate at a level corresponding to a peak reactor flux of about 5×10^6 n/cm² s. The extrapolation of the standard approach to critical curves *(4)* indicated a critical size of 411·6 channels which agreed very closely with the critical size of 412 channels for Calder reactor no. 3. The performance of the reactor during this stage was observed by

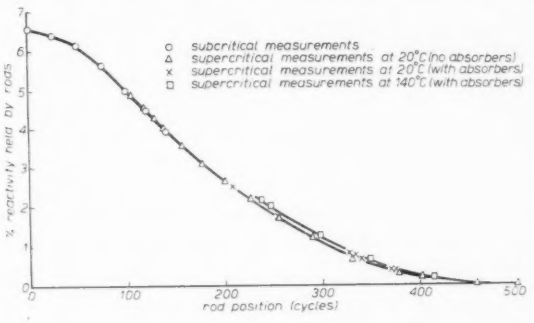
a. Four BF_3 proportional counters positioned in the top reflector with the counting equipment on the reactor cap.
b. Three shut-down amplifier chains which were the standard full power operating equipment with their ion chambers positioned temporarily in the top reflector and with suitable high resistors to cover the range of sensitivity required. The shut-down amplifiers were located in their operational position in the reactor control room.
c. Two period-meter chains with their ion chambers in the top reflector connected to installed reactivity instruments in the reactor control room.

The cables to the BF_3 proportional counters were passed into the vessel through a wooden flange mounted on a charge tube. The cables to the shut-down amplifiers and period-meter chains were passed through a special pressure tight flange on a charge tube since these instruments were to be used later when the vessel was at less than atmospheric pressure. All of this equipment had been assembled and put on 'soak test' for some months before the loading to critical size began.

2. Measurements round the critical size

Starting on November 10, 1958, the reactor was successively loaded to 420, 424 and 428 channels and measurement was made of the effect on reactivity of the number of channels loaded. The results of the measurements may be seen in Figure 1 and it is to be noted that extrapolation back to the critical size gave 411·8 channels. During these measurements four ion chambers in the top reflector were connected to an equipment which measured automatically a $\sqrt{10}$ folding time of the ion chamber signal and four to an equipment which enabled a doubling time to be measured by stop watch. At this stage of the programme, when the ion chambers were in the reflector and reasonably high currents were achieved with a very moderate core neutron flux, both types of equipment were satisfactory and consistent one with the other. At later stages of the programme when the ion chambers had to be located in the thermal column and were giving smaller currents some difficulty was experienced with the automatic equipment.

The axial and radial flux plots made in the Calder reactors to determine the Laplacians and extrapolation lengths were not repeated at Chapelcross because it was considered that the parameters were sufficiently well established. Partial calibration of the control rods was made, however, at each of the three stages of loading above critical by holding the reactor balanced at a steady neutron flux by one and then two control rods. The calibration points for the new control rods in use in this reactor fell on the theoretical curves drawn up prior to the calibration. The expected calibration was posted in the reactor control room and the results were plotted on the same graph by the technical section as soon as the measurements were made. The excellent agreement helped the 'new' operations shift teams to have confidence both in the work they were doing and

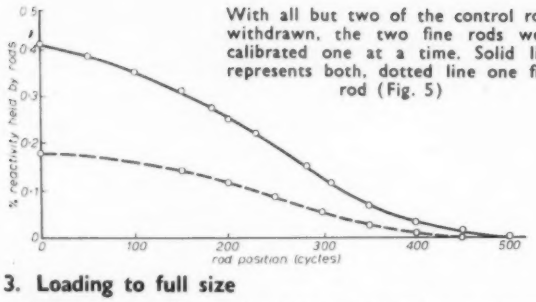


To calibrate the 48 control rods the vessel was sealed, pressurized with air and the loss of reactivity balanced by withdrawing the rods (Fig. 4)

in the technical section, and also helped the 'new' technical section to have confidence in the operators and themselves.

When the reactor was loaded to 428 channels one channel of uranium was replaced by a channel of steel absorber cartridges. The reactor was sealed and the air pressure reduced to about 50 cm of mercury pressure. On withdrawing the control rods the reactor diverged with a doubling time of about 60 seconds, thus enabling a calculation to be made of the effectiveness of this absorber. A pressure coefficient measurement was made by reducing the air pressure in three increments of about 3 cm of mercury each and measuring the doubling time after each increment. On completion of the pressure coefficient measurements the vessel pressure was returned to atmospheric and the channel of steel replaced by a channel of cobalt and the measurement of the effectiveness of this absorber made.

During these determinations the maximum reactor power reached was about 1 kW and the health physics surveys indicated that there was no limitation on the working time in the vessel at charge pan level after these irradiations. At the conclusion of these measurements at or near the critical size the operators were much more familiar with their plant and the technical section had confirmed that the first Chapelcross reactor was behaving in a manner exactly similar to Calder Hall.



With all but two of the control rods withdrawn, the two fine rods were calibrated one at a time. Solid line represents both, dotted line one fine rod (Fig. 5)

3. Loading to full size

Before proceeding to load the critical size reactor to full size the fast rate of withdrawal modification to the coarse control rod mechanism was removed. All but two of the control rods were fully in and their withdrawal mechanisms locked off. The two remaining control rods were put on to the fine control rod withdrawal mechanism and were held fully out at 'emergency shutdown capacity.' The loading was controlled by the reactor foreman and was carried out in accordance with a master copy of the loading schedule provided by the technical section. Diagrams of the state of loading which were started when loading to critical size began were continued and were displayed on reactor cap and reactor control room. During the whole of the commissioning period all loose equipment used in the vessel or on pile cap near an open charge hole was fitted with a safety ring or lanyard so that it could not fall down a channel, and all equipment and tools that were taken into the vessel were logged in and out on each shift.

The first steps in loading to full size were to complete the charge groups which had been partially loaded because radial symmetry had been maintained. This was carried out by hand loading as described earlier. The subsequent loading to full size was done with the charge machines and took from November 13 to 23, 1958. An activated antimony-beryllium neutron source was loaded into the reactor at this stage in order to increase the observed neutron count rates in the thermal column during subsequent measurements.

4. Calibration of the control rods

During the initial stages of commissioning four control rods in excess of the operational complement (48) were loaded in order to guarantee adequate shutdown capacity under all conditions. A measurement to determine how many of the 52 control rods could be removed safely was carried out immediately after the completion of loading to full size. The BF_3 proportional counters previously located in the top reflector were now removed from the reactor core and repositioned in the thermal column. The count rate was determined with all the control rods fully in and then rods were withdrawn initially in pairs and then singly, and the count rate recorded after each withdrawal. The number of rods required to be withdrawn for criticality was found by extrapolating the curve of reciprocal count rate against number of rods in the reactor (Figure 3). The measurements confirmed that adequate control was provided by the operational complement of 48 rods and the four additional rods were then removed from the reactor.

The technique for the calibration of the control rods was similar to that used for the Calder reactors. In the supercritical region the calibration consisted of pressurizing with air and balancing the loss of reactivity due to the neutron absorpton of the nitrogen in the air by withdrawing the control rods. In the subcritical region the calibration was made by measuring neutron count rate for different control rod positions.

To begin the calibration in the subcritical region the vessel was completely sealed and exhausted to a nominal pressure of 12 cm Hg. With all of the 48 rods fully inserted a measure of the neutron flux was made by means of the two BF_3 counters in the thermal column. Further measurements were made with all 48 rods in line at positions up to 100 cycles withdrawn (1 cycle is equivalent to approximately 1 cm of rod movement). The reactor diverged and was held balanced at 104·8 cycles. The procedure was repeated at nominal pressures of 50, 76, 100, 150 and 200 cm of Hg.

The calibration in the supercritical region began at a nominal air pressure of 12 cm of Hg and continued until the control rods were fully removed from the core when the reactor was held balanced by an air pressure of 531 cm of Hg. The results of this calibration together with the subcritical calibration are shown together in Figure 4. At a later stage in the commissioning programme, when the whole of the reactor vessel and gas circuit was filled with air at 140°C, the supercritical calibration of the 48 control rods was repeated in the manner described above. The results of this calibration are also plotted in Figure 4.

The method adopted to calibrate the fine rods was to pressurize the reactor to 512 cm of Hg and withdraw all but two of the control rods. One of the two was then left in a known position and the second rod was rapidly withdrawn from the core. The reactor diverged and the reactivity available was measured by determining a doubling time. The reactor was shut down by running in both of the two rods at maximum speed. The calibration of two fine rods was achieved in similar manner. The results are shown in Figure 5.

5. Hot gas circuit and b.s.d. gear tests

Of the two main tests which then remained to be done on the reactor the first was a gas circuit pressure test at 140°C. The circuit was charged with air and heated from construction site steam fed into the heat exchangers and from the heat developed in the four carbon dioxide blowers run at normal full power operating speed. At the conclusion of these tests, which had also permitted the calibration of the control rods hot, the circuit was cooled down for a final internal and external plant inspection. This completed, the burst cartridge detection gear was subjected to the same type of tests as those carried out at Calder Hall. Enriched uranium foils were loaded into channels, the reactor

raised to power and the signal received by the gear recorded. The results were similar to those achieved at Calder Hall, the gear possessing the same excellent sensitivity *(6, 7)*.

These tests are carried out after the so-called final inspection because the power level to which the reactor is taken is such that subsequent entry to the reactor vessel is limited by the gamma radiation from the core. Extreme care is therefore taken in handling the foils when removing them from the vessel since the latter is then finally sealed.

6. Reactor to power

After certain other experiments not reported here the reactor was raised to full power in two steps between January 6 and 9. The manner of operation followed exactly the procedure developed at Calder Hall *(6)* and the plant operating instruction were followed in detail. A steady power a little in excess of 200 MW was achieved and has been maintained. Although the operators were bringing the reactor to power for the first time it was clear that they had benefited considerably from simulator training at the Calder Operations School and from having been in executive control throughout all of the physics measurements. From this time onward the reactor was available for full power operation and became the servant of the steam plant for its commissioning. Figure 7 illustrates the variations in plant conditions during a subsequent normal reactor start-up.

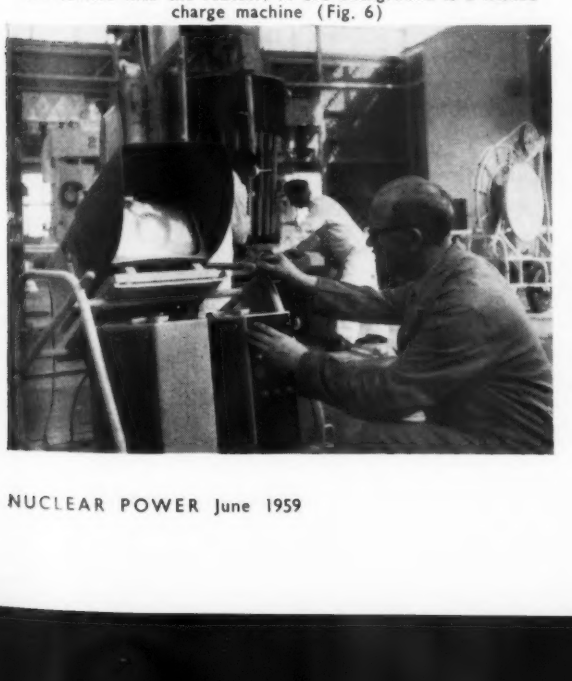
POWER PLANT COMMISSIONING

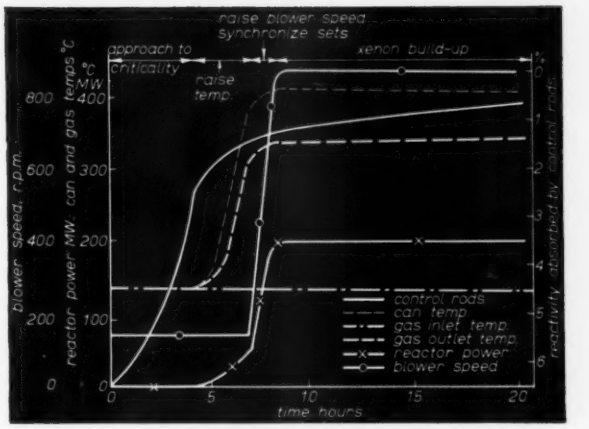
During the reactor commissioning the power plant operators took over from construction and operated :

1. the condensate plant
2. the feed water system and demineralization plant
3. the heat exchangers
4. the h.p. and l.p. auxiliaries, steam mains and desuperheater water heater.

The main steam circuits were thermal cycled on construction site steam and steam was provided to the reactor both for the hot run with air in the circuit and also to provide the initial heating to 140°C of the reactor core when CO_2 was first introduced.

Closed circuit television is used for inspecting charge channels in the pile. Far right is the cable carrier which lowers the camera into the reactor; in the background is a loaded charge machine (Fig. 6)





During a typical start-up of reactor 1, these variations in plant conditions occur (Fig. 7)

When the reactor first went to power steam was fed to the dump condenser and the steam safety valves were floated. On January 10 the h.p. and l.p. steam lines were blown to atmosphere four times through temporary blow-off pipework. This was to ensure the cleanliness of the steam system prior to passing steam to the turbo-alternators. During the ' blow-offs ' the feed regulators maintained the system reasonably steady and the temperature of the inlet gas to the reactor varied only by about 5°C. The rest of the reactor core was virtually unaffected.

The reactor was shut down from January 11 to 25 to permit a detailed examination of all the steam circuit valves, traps, etc. to remove any foreign matter. After reassembly of the steam circuits the reactor was brought to power and the system was blown to atmosphere through the temporary blow-off pipework again until four consecutive blows left the polished etching plates in the blow-off lines unmarked. This was taken to be a measure of the cleanliness of the circuit concerned and of its freedom from foreign matter. The blows to atmosphere, the removal of the temporary pipework and the reinstatement of the system was completed by February 16 when commissioning by C. A. Parsons & Co. Ltd. of the turboalternators started. This followed the conventional procedure of 1. running up mechanically; 2. overspeed tests; 3. bearing inspection; 4. dry out of the alternator; 5. electrical tests on alternator; 6. alternator protection set up. The no. 1 turboalternator was synchronized onto the grid on February 21, 1959, and the no. 2 set on February 28, 1959.

Acknowledgment :
The permission of the Managing Director of the UKAEA Industrial Group, Sir Leonard Owen, KBE, to publish this account is acknowledged.

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7. Davey, H. G. ' Commissioning and operation of " A " station, Calder Works,' *BNEC Jour*, 1958, *3* (2) April

POWER. In each reactor, four of these heat exchangers feed two turbines, giving 46 MW output

CHAPELCROSS

Industry's Share

This station, designed by the Production Reactor Design Office of the AEA, necessitated the placing of some 2000 contracts having a total value of £M34, on British Industry. Over 1700 contracts were issued by Risley for materials and equipment similar to that employed on the Calder Hall installation and Merz & McLellan, the consulting engineers appointed by the Authority, issued more than 240 contracts for civil, mechanical, electrical and service equipment not a direct copy of the Calder Hall items.

Main consultants and contractors

MERZ & McLELLAN
Consulting engineers

W. V. ZINN & PARTNERS
Design of turbine house steel frame

L. G. MOUCHEL & PARTNERS LTD
Design of cooling towers

L. J. COUVES & PARTNERS
Architects for administrative buildings, canteen and housing schemes

MITCHELL CONSTRUCTION CO LTD
General civil work contract

C. A. PARSONS & CO LTD
Turbo-generating plant contract

STEWARTS & LLOYDS LTD
Main contractor for the supply, erection and welding of the pipework systems

THOS. W. WARD LTD
Mechanical dayworks contractors for installation of plant and machinery and operation of site mechanical facilities.

AEA Major Contracts

ACCLES & POLLOCK LTD
Stainless steel tubing

ACCURATE RECORDING INSTRUMENT CO LTD
Instrumentation

AEKIALITE LTD
Cables

AIRSCREW CO & JICWOOD LTD

AITON & CO LTD
Pipe work

APPLEBY & IRELAND LTD
Control rod indicators

THE APV CO LTD

ARMSTRONG WHITWORTH (METAL INDUSTRIES) LTD
Pressure vessel shield plugs & wall seal assemblies

BABCOCK & WILCOX LTD
Heat exchangers

SIR W. H. BAILEY & CO LTD
Valves

BAILEY METERS & CONTROLS LTD

BAKER PLATINUM DIV OF ENGELHARD INDUSTRIES

WILLIAM BEARDMORE & CO LTD
Steel plates for thermal shield

HENRY BERRY & CO LTD

J. BLAKEBOROUGH & SONS LTD
Gas valves & control gear

BRITISH ALUMINIUM CO LTD

BRITISH ERMETO CORPORATION LTD
Pipe fittings

BRITISH INSULATED CALLENDER'S CABLES LTD
Multi-core & special fuel element handling cables

BURNDEN PARK ENGINEERING CO LTD
Charge pen components

BURTONWOOD ENGINEERING CO LTD

THE BUTTERLEY CO LTD

W. P. BUTTERFIELD LTD
Irradiation hood tubes & liners

WILLIAM H. CAPPER & CO LTD
Pipe work

CHATWOOD MILNER LTD
Reactor components

CONCORDIA ELECTRIC WIRE & CABLE CO LTD
Cables

CONSETT IRON & STEEL CO LTD
Mild steel plates

CONSOLIDATED PNEUMATIC TOOL CO LTD

CONSTRUCTORS JOHN BROWN LTD

COSTAIN-JOHN BROWN LTD
Heavy lifting gear

J. A. CRABTREE & CO LTD
Switchgear

CRAVENS LTD
Shield plugs & skips

CROSSLEY BROTHERS LTD
Standby diesel generating sets

J. DAY & CO (DERBY WORKS) LTD

DELEPENA & SON LTD
Induction heating equipment

DEWRANCE & CO LTD
Mounting & valves

DISTINGTON ENGINEERING CO LTD
Shield cooling stacks & transport coffins

DOULTON INDUSTRIAL PORCELAIN LTD

TIMOTHY EATON & PARTNERS

EKCO ELECTRONICS LTD
Nucleonic instrumentation

ELLIOTT BROS (LONDON) LTD
Burst slug detection gear, recorders & transmitter gauges

EMPYRIUM WELDING & MANUFACTURING CO LTD

THE ENGLISH ELECTRIC CO LTD
Control equipment

ENGLISH STEEL FORGE & ENGINEERING LTD
Steel plate for thermal shield

ERF LTD
Transport vehicles for coffins

EVANS LIFTS LTD
Lifts for reactor buildings

EVERSHED & VIGNOLES LTD
Control instrumentation

FAIREY AVIATION CO LTD
Graphite restraint equipment

FAWCETT, PRESTON & CO LTD

FILM COOLING TOWERS (1925) LTD
Water coolers for auxiliary circuits

FOXBORO-YOXALL LTD
Instrumentation

JAMES GIBBONS LTD

SIR HOWARD GRUBB, PARSONS & CO LTD
CO_2 in water detectors

HADFIELDS LTD
Control & shut-off rods

HENRY HARGREAVES & SONS LTD
Ducting

HICK HARGREAVES & CO LTD
Deaerators

HAYWARD TYLER & CO LTD
Glandless pumps

HEATHER FILTERS LTD
Air filters

HONEYWELL-BROWN LTD
Recorders

JAMES HOWDEN & CO LTD
Shield cooling fans

IMPERIAL CHEMICAL INDUSTRIES LTD
Stainless steel pipework for burst slug detection

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GEORGE KENT LTD
Recorders & instruments

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RICHARD KLINGER LTD
Cocks for burst slug detection gear & joints

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Accounting machinery

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Discharge machine magazine air drier

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STRACHEN & HENSHAW LTD
Reactor charging & discharging machines & cartridge cooling pond equipment

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UNSWORTH & SONS LTD

T. T. VICARS LTD

VICKERS ARMSTRONGS (AIRCRAFT) LTD

VOKES GENSPRING LTD
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Flux scanning gear

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OET cranes

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Reactor pressure vessels

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Cast iron coffins

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WINGROVE & ROGERS LTD
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Merz & McLellan Contracts

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DUMFRIES COUNTY COUNCIL
Section of effluent drain to Solway and water main to temporary housing site

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DARLINGTON FENCING CO LTD
Site fencing & gates

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Structural frameworks

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Administrative and police buildings

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JAMES M. WELLS & CO LTD
Erection of houses & garages, superstructures for administrative, laboratory, fuel element & general stores buildings

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COCHRAN & CO (ANNAN) LTD
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Water treatment plant & degreasing plant

INTERNATIONAL GAS DETECTORS
CO_2 plant indicating alarms

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5-ton blocks

THE KLEEN-E-ZE BRUSH CO LTD
Condenser tube cleaning equipment

E. N. MACKLEY & CO
Special tools & tongs

METERING PUMPS LTD
Pumps & equipment

W. & E. MOORE LTD
Electric hoist blocks

HERBERT MORRIS LTD
Roller conveyors & auxiliary hoisting equipment & blocks

MUNRO & MILLER LTD
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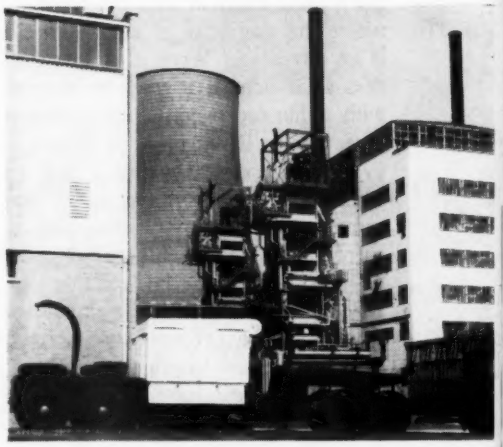
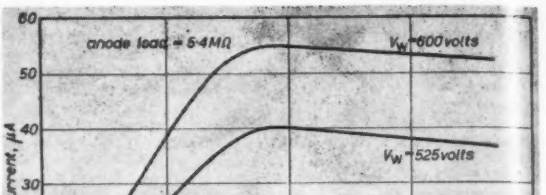


The last article in this series shows how the instruments described in previous issues are used in research and industry

RADIATION DETECTORS

4—Some applications

by W. R. LOOSEMORE, *B.Sc., A.R.C.S.*
A.E.R.E., Harwell



Response of a high-current G.M. counter to gamma radiation from Co-60 (Fig. 1)

Geiger counters

The G.M. counter has no intrinsic ability to discriminate between different classes of radiation: a single ion pair produced in the sensitive volume of a counter will result in a complete electron avalanche. The total charge collected at each discharge will vary from 10^{-11}–10^{-10} coulombs for an organic-vapour-quenched counter to 10^{-9}–10^{-8} coulombs if the counter is a low voltage type quenched with bromine or chlorine. The life of a halogen-quenched counter is very long since the quenching agent is not destroyed during the ionization process, whereas an organic-vapour-quenched counter has a life of 10^{8}–10^{9} counts. Operating voltages range from 300–500 volts for low voltage counters to 1000–1500 volts for the others. The resolution of all G.M. tubes is of the order 10^{-4} seconds, and hence counting rates are limited to a maximum of 10^{3}/s if large losses are to be avoided.

Applications of G.M. counters are thus limited to cases where no information is required about the energy or nature of the radiation to be measured, though the use of external absorbers may enable information to be deduced. This type of counter is commonly used for the routine assay of beta-active solid or liquid samples where the simplicity of associated electronic apparatus is an advantage. When a sample can be prepared as a thin solid deposit it may be assayed using a counter with a thin end window; measurement of bulk samples, especially in liquid form, is usually accomplished by a cylindrical counter having a thin wall which can be wholly or partially immersed in the sample. A small sample of liquid may be contained in an annular space surrounding such a thin-walled counter by a suitably designed jacket. The low efficiency to gamma radiation enables a counter of usable dimensions to be produced with a low background count rate. As an example a counter of active length 1 in. with an end window 1 in. in diameter will have an unshielded background of about 20–30 c/min in clean surroundings, whereas a scintillation counter with a crystal of similar dimensions will have a background of 1500–2000 c/min.

Counters are available with mica end windows up to 2 in. diameter and of thickness down to 2 mg/cm²; aluminium alloy windows are commonly 7 mg/cm². Counters used for the assay of liquids are made of glass, the wall thickness being 30–40 mg/cm² over a length of 6 or 12 cm; the liquid capacity of these counters is 10–20 ml.

Low voltage counters find their chief application in portable apparatus, for instance in geological survey or Civil Defence instruments where robustness and long life are more important than extreme sensitivity or accuracy. Gamma counters for this application have been designed which are able to withstand a 4 ft drop on to concrete. By suitable design it is possible to increase the charge collected per counting event to a level where the mean current through the counter may be measured directly with a conventional microammeter, forming the basis of a simple radiation monitoring equipment. Figure 1 shows the response of such a counter to gamma radiation from Co-60 (1·1 and 1·3 MeV) over a wide range of dose-rates. The dimensions of this counter are 10 mm dia. × 4 cm long, excluding terminations.

Energy measurement by proportional counters

The gas ionization proportional counter has many applications since it offers the possibility of measuring the energy of an incident radiation. However it is also commonly used to assay alpha and beta radiation even when an energy analysis is not required, since the resolving time depends only on electron mobility in the filling gas and hence may be reduced to less than 10^{-6} second. The counting gas, which may be argon or argon + 10% methane, is flowed through at atmospheric pressure so that it is not necessary to seal the counter envelope. This in turn enables a source to be placed inside the counting volume, eliminating window absorption. If pure argon is used, the gas multiplication

is limited to about 100 for reliable operation, before secondary effects at the cathode result in a continuous discharge. With normal amplifier settings this restricts the proportional counter to the detection of alpha particles. If 10% methane is added to the argon the gas gain increases exponentially with applied voltage up to values greater than 10^4, showing that secondary cathode effects are unimportant at this level.

Alpha-active samples are often contaminated with fission products emitting beta and gamma radiation and in this case the energy discrimination of the proportional counter can reduce the effect of this contamination.

Let E_a = the minimum energy dissipated by an alpha particle which will result in detection,

E_b = energy dissipated by a beta particle in traversing the counter, assumed constant ($E_b \ll E_a$).

n = occurrence rate of events resulting in E_b

τ = resolving time of counter.

Then if $n\tau \gg 1$, the energy dissipated in the counter in time τ due to E_b will be $E_b n\tau$, and the standard deviation $E(n\tau)^{\frac{1}{2}}$. It can easily be shown that if $E_a/E_b(n\tau)^{\frac{1}{2}} = p$, the probability that the fluctuation will exceed E_a and thus result in a count is $5{\cdot}9 \times 10^{-7}$ if $p = 5$ and 2×10^{-8} if $p = 6$.

Typically $\tau = 5 \times 10^{-7}$ s, $E_a/E_b \simeq 40$ for the type of counter under discussion, and the spurious count rate will be 1 c/s for $n = 1{\cdot}3 \times 10^8$ c/s if $p = 5$, or 0·004 c/s for $n = 10^8$ c/s if $p = 6$; thus quite a large beta contamination may be tolerated.

Since the specific ionization of beta particles increases with decreasing energy the amplifier gain necessary to detect beta particles will correspondingly decrease, or alternatively if the amplifier gain is fixed the counter anode voltage required at the threshold will decrease. A normal beta operating voltage for the flow counter discussed is 1500 volts, when the threshold of detection is about 100 primary ion pairs produced in the counter.

Use in X-ray fluorescence spectroscopy

The ability of proportional gas counters to detect low energy X-ray photons was mentioned in a previous article (*1*), and has recently been extended to the field of X-ray fluorescence spectroscopy. Conventionally, radiation from an X-ray tube falls on the specimen under investigation and the fluorescent X-rays so produced are analysed in a crystal spectrometer. By replacing the X-ray tube with a radioactive source and the crystal spectrometer by a proportional counter, the radiation hazards may be greatly reduced due to the more favourable geometrical arrangements which are possible, and the apparatus considerably simplified.

The scintillation counter may also be used in this application, but for energies below 100 keV the poor resolution of the latter is a serious disadvantage. The energy required to produce 1 ion pair in a gas is about 30 eV, and hence absorption of a titanium X-ray of 4·5 keV gives a number of ions $N = 150$, with an approximate fractional standard deviation $= 1/(150)^{\frac{1}{2}}$. The fractional width of the photoelectric absorption peak at half-maximum amplitude is therefore $2{\cdot}36/(150)^{\frac{1}{2}}$ or 29·5%. The light output from a NaI(Tl) crystal and photomultiplier is 1000 photoelectrons/MeV absorbed and hence an average of 4·5 photoelectrons will be released per titanium X-ray photon. The resolution is therefore worse by a factor $(150/4{\cdot}5)^{\frac{1}{2}} = 5{\cdot}9$.

The technique can be applied to detect the presence of elements or mixtures of elements by identifying the energy of the appropriate fluorescence radiation, but fluctuations in the number of primary ion pairs produced will only enable elements to be resolved in a practical design of counter (*2*) if they are separated by at least 3 units of atomic number for $Z<40$; for $Z>40$ a separation of 4 units is required. If the energy of the fluorescence radiation is greater than that of the *K*-absorption edge of the counter gas then the spectrum will include an escape peak of energy $E\gamma - E_k$, and this may be used to identify elements which cannot be resolved directly.

While alpha- and beta-emitting sources have been used to excite fluorescence X-radiation, the X-ray sources Fe-55 (5·9 keV), Cs-131 (30·8 keV) and W-181 (58 keV), with half-lives of 2·9 years, 10 days and 140 days, are perhaps the most convenient. The source is often mounted in an annular ring made of lead surrounding the counter window to absorb radiation emitted directly and the sample is placed immediately above it. Fluorescence X-rays from the sample excited by the incident radiation then enter the counter and are detected. In addition to the analysis of both liquid and solid samples the thickness of surface coatings may be measured by this method.

Another application of the X-ray proportional counter lies in the study of X-ray emission from the alpha-emitting trans-uranic elements. The nuclear structure of such elements may be studied by examination of fine structure in the alpha-particle spectrum, but this requires a highly sophisticated technique and a gridded ion chamber operating very close to the theoretical limit of resolution. It may be much simpler to identify this fine structure by measurement of nuclear X-radiation which usually occurs in the energy range around 20–100 keV.

It should be noted that as pulse amplitude is used to determine the energy of a photo-peak it is important that the overall voltage gain of the system be constant over long periods. It is relatively easy to stabilize the gain of an amplifier to $\pm 1\%$ over periods of hours, but stringent demands are placed on the stability of the h.t. supply to the counter. Gas amplification in a proportional counter is an exponential function of applied voltage, and with mixtures of a rare gas at 40–150 cm Hg and 5–10 cm CH_4 and an anode wire diameter of 0·1 mm, a change in e.h.t. of 1% will result in a change in pulse height of 14–20%. Thus the stability required of

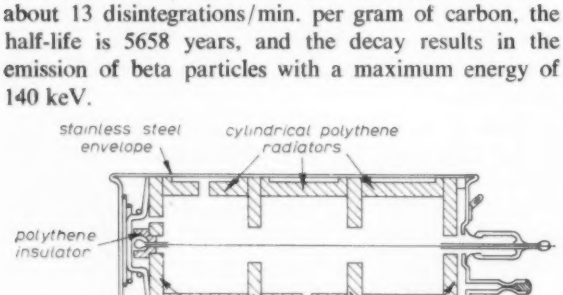
the e.h.t. supply is at least ±0·1%, and it is usual to make frequent stability checks with radiation of a known energy.

Assessing fast neutron health hazard

The gas proportional counter has also been used (*3*) to assess the health hazard due to a flux of fast neutrons in the energy range of 0·1–15MeV (Figure 2). It takes the form of a series of polythene-lined cells placed in line, with a common anode wire of tungsten 0·001 in. dia. passing along the axis of each cell; the gas filling is a mixture of methane and argon. The principle is that incident neutrons will make elastic collision with protons contained both in the hydrogenous material of the wall and in the gas and the ionization produced by recoil protons as they traverse the gas can be collected and measured. The amount of energy expended in the gas by a proton will depend in a rather complicated way on the energy of the incident neutron, the angle between the recoiling particles, the gas pressure, and the thickness of the hydrogenous radiators. However it has been found possible to adjust these parameters so that the sensitivity of the counter to a flux of neutrons is proportional to the biological dose per neutron within ±20%. Thus the counting rate is a direct measure of the fast neutron hazard, independent of neutron energy, in the range of 0·1–15 MeV. The count rate of a typical counter containing three cells is 0·7 c/s for one maximum permissible level (m.p.l.) of fast neutrons, i.e. a flux which would produce a dose rate of 7·5 mrem/h in the body. An equivalent count rate is produced by 200 m.p.l. gamma radiation or 100 m.p.l. thermal neutrons.

Assay of low activity levels

A further application of gas ionization counters involving both G.M. and proportional counters is in the assay of samples having a very low activity, a particular example of great interest being the estimation of the age of carbon-containing specimens by assay of the C-14 content. The principles of the method are well known (*4*) and need not be discussed here, except to note that the specific activity of 'living' carbon is about 13 disintegrations/min. per gram of carbon, the half-life is 5658 years, and the decay results in the emission of beta particles with a maximum energy of 140 keV.



Fast neutron proportional counter consists of a series of polythene-lined cells with a common tungsten wire anode (Fig. 2)

The method normally adopted for the measurement of this activity is to convert the sample to a gas, usually CO_2, C_2H_2 or CH_4, which can be used as the filling gas of a proportional counter. The volume of gas may vary between 0·5–5 litres at s.t.p., and the gas pressure will be between 35 and 220 cm Hg, so the counter will have a volume of 0·5–2 litres. The total disintegration rate of a sample 22,000 years old will be 0·8 d.p.m. for 2 litres of CO_2 or 1·63 d.p.m. for a similar volume of C_2H_2. Since the unshielded background of such a counter will be approximately 300–1000 c/min, the problem is essentially one of reducing the background by a factor of 400. This problem is, of course, not peculiar to radiocarbon dating.

The background count-rate will be due to three causes, excluding any spurious effect produced by the amplifying and recording circuits:

1. Cosmic radiation
2. Natural activity of the surroundings, including the material of the shield
3. Activity of the materials of which the counter is constructed.

The first two make roughly equal contributions to the total background, and are very much greater than the third. The cosmic ray component of background is largely due to energetic charged particles—mesons—which are detected with almost 100% efficiency by the counter, although their range is very much greater than the dimension of the counter. Thus if the sample counter is surrounded completely by a ring of G.M. counters having a filling pressure high enough to detect the passage of a meson with 100% efficiency, two pulses will be produced coincidentally in time as the particle passes through at least one counter in the ring and the central sample counter. It is arranged electronically that only those pulses from the sample counter are accepted which are not accompanied by a coincident pulse from a counter in the 'anti-coincidence' ring which may be a number of separate counters or a composite counter with multiple anodes in a common envelope. G.M. counters are employed since the large pulses produced require very little amplification, and the dead-time losses are insignificant at the background counting rates of 1–5 c/s.

Gamma radiation due to the surroundings may be reduced by surrounding the counter and its anti-coincidence ring by a large mass of material which is itself free from contamination. Lead may be used, but 'modern' lead will contain RaD (22 years half-life) and its daughters RaE and RaF, and there is a significant contribution to the counter background due to *Bremsstrahlung* from RaE. Thus lead purified 150–200 years ago must be used. A common alternative material is mild steel, though it is usually necessary to assay samples from each batch for freedom from Co-60 before the shield is assembled, to a total thickness of up to 20 cm. Any residual gamma activity produced by mesons stopped in the shield or by contamination of

the anti-coincidence counters, may be eliminated by surrounding the sample counter with a 2·5 cm thickness of pure Hg inside the anti-coincidence ring. The total weight of such a shield for a counter of 0·6 litres volume at s.t.p. is approx. 6 tons.

Contamination produced by the sample counter itself can only be eliminated by careful attention to the constructional materials, and by assembling in a laboratory which is free from activity. Nickel-plated mild steel has been used with success, as has stainless steel, though the best solution is probably that of de Vries, who uses an oxygen-free copper vacuum envelope containing a pure silica liner having a thin film of gold on the inner surface to produce a conducting cathode surface. Insulating materials are often a source of contamination, due for instance to K-40 in glass and in many ceramics. The insulator assemblies have to be carefully designed to minimize the effect of this contamination. The resultant background of a counter with a volume of 1 litre at s.t.p. will be 1–3 c/min.

To examine the relative importance of the background and net sample count rates, B and S, respectively, assume that S is small compared with B and that equal times are spent in counting the background and sample. Then the fractional error in the net sample rate is

$$\frac{\sigma_s}{S} = [(S + B)t + Bt]^{\frac{1}{2}}/St,$$

where σ_s is the standard deviation and t is the counting time. It can then be shown (*5*) that if B_1, S_1 are initial figures and B_2, S_2 are obtained by alteration of some parameter, the counting statistics will be improved if

$$\frac{B_2}{B_1} < \frac{(S_2/S_1)_2(1+2B_1/S_1 - S_2/S_1)}{2B_1/S_1}$$

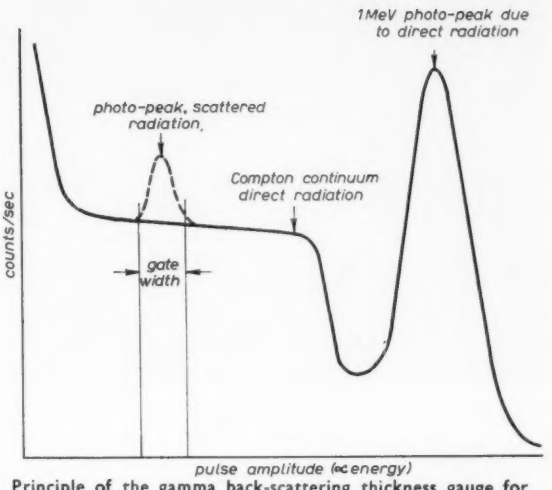
and in the limit, when $S_1/B_1 \rightarrow 0$, this reduces to

$$S_2^2/B_2 > S_1^2/B_1$$

The background can therefore be allowed to increase as rapidly as the square of the sample activity even in this worst case. If $S_1/B_1 > 0$ the increase can be even more rapid, so that it may be more profitable to devise means of increasing the sample count rate rather than to decrease the background to the lowest figure possible.

Thickness gauging

One field of great industrial interest is the measurement of thickness of moving material without direct contact with the material. Since the techniques illustrate the usefulness of several types of radiation, it is instructive to consider them here. The simplest type of thickness gauge only gives information concerning the presence or absence of the material, as might be required on a package filling line when cartons that have inadvertently been left empty must be rejected. This simple test may be accomplished by arranging for the line of packages to pass between a beta-emitting source and a G.M. counter, when an empty package will produce less attentuation of the radiation than a full one. The simplicity of operation of the G.M. counter can



Principle of the gamma back-scattering thickness gauge for fairly thick material with access on one side only (Fig. 3)

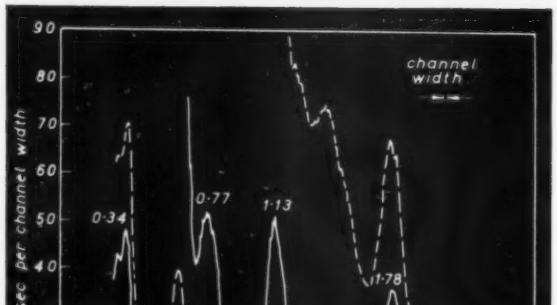
be utilized and accuracy or stability are not required since the device merely acts as a switch.

Certain industries have been interested in monitoring continuously their products: in particular in paper making and coating, plastic sheet production, linoleum making and metal rolling. In these cases, where the detector must be rugged and extremely reliable, the beta-sensitive ionization chamber is used (*6,7*). Where both sides of the product sheet are accessible a strip of beta emitter (Tl-204) is placed on one side and the ion chamber on the other. By suitable choice of source the response of the ion chamber can be made to vary roughly logarithmically with the weight per unit area of absorbing material. Provided that the voltage applied to the ion chamber is sufficient to allow complete collection of the maximum current in the absence of any absorber, the main sources of error arise due to variations in the high value resistor at the input to the d.c. amplifier and to statistical fluctuations in the ion current. By placing the source and ion chamber on the same side of the sheet and detecting back-scattered beta radiation it is possible to measure the depth of a thin coating of one material on another, but the source strength has to be greatly increased, and the fluorescence X-ray technique discussed earlier affords a more elegant method of achieving the same object.

For the measurement of comparatively thick material e.g. the thickness of metal plate or pipes, where access is limited to one side, the reduction of energy of gamma-radiation following Compton scattering can be used in conjunction with a scintillation counter (*8*). When a gamma photon of energy $E\gamma$ is scattered through 180° the energy of the scattered photon $E'\gamma$ is given by

$$E'\gamma = E\gamma/(1 + 4E\gamma)$$

As $E\gamma$ increases, $E'\gamma$ approaches a maximum value of 0·25 MeV, and for high values of $E\gamma$ (> 0·75 MeV) the variation in energy of the scattered quanta is small, but the difference in energy between incident and scattered quanta is large. Thus if a 1 MeV gamma source is



Spectrum of Ra gamma rays taken with two-crystal gamma spectrometer (Fig. 4)

placed close to the material whose thickness is to be measured and a scintillation counter arranged behind the source on the same side of the sheet, the pulse height spectrum will show a large peak at 1 MeV corresponding to photoelectric absorption of the direct radiation and a smaller peak at 0·2 MeV corresponding to photoelectric absorption of the back-scattered quantum superimposed on the Compton distribution of the incident radiation (see Figure 3).

Since these energies are widely different no difficulty arises in separating them even without shielding from the primary radiation. The discriminator and ratemeter circuits accept only those pulses corresponding to the scattered radiation photo-peak, and variations in this output may be related to material thickness. By making this gate fairly narrow only those photons are detected which have been back-scattered through 180° and hence the device is self-collimating. This confines the measurement of thickness to a small area, and hence local fluctuations due to corrosion pitting in pipes may readily be detected, using a 20μc source of Co-60. The apparatus may be made easily transportable.

Gamma scintillation spectrometry

An important general application of the scintillation counter is in gamma-ray spectrometry, since the detection efficiency of a NaI(Tl) crystal is high even at photon energies of 2–5 MeV, and this is coupled with good energy resolution above 200 keV: a typical figure is 7·5% full width at half maximum height at 0·66 MeV. This figure applies to the photoelectric absorption peak, but in a spectrum containing several such peaks the problem of identification is complicated by the presence of a Compton-scattered continuum for each gamma ray in addition to the main peak. This has the effect of increasing the background count rate at lower energies which may mask other low intensity photo-peaks.

The difficulty may be overcome by the use of large crystals to decrease the probability of escape of the scattered photons, or by coincidence cancellation of the Compton photons with another crystal, but a less expensive and simpler method is to expose the gamma-ray source simultaneously to sodium iodide and anthracene scintillation counters (*9*). The mean atomic number of anthracene is much less than that of sodium iodide and hence the photoelectric effect is unimportant except at very low energies so that absorption of energy takes place largely by the Compton scattering process. The Compton continua from the two crystals are matched in energy (pulse height) by adjusting the supply voltages to the photomultipliers, and in count rate by adjusting the position of the source between the two crystals. Outputs from the two counters are subtracted electronically so that each gamma energy is represented only by a photoelectric peak in the recorded spectrum. The effect of this technique is clearly shown in a study of the gamma rays from radium (Figure 4).

It is possible to use the method for radioactivation analysis of a sample without recourse to chemical methods. As an example, by irradiating a 1 g specimen of 'super-pure' aluminium in Bepo and plotting the resultant gamma spectrum at different times after irradiation, the presence of 10^{-5}–10^{-6} g of manganese, gallium, copper, hafnium and scandium could easily be detected (*10*). Another example of this method is an analysis of the gamma spectrum of fission products from slow neutron irradiation of U-235 (*9*). An 0·006 g sample was irradiated, and the spectrum plotted at various times up to 1000 hours after irradiation. An examination of the energy of a peak and its rate of decay enabled seventeen activities to be positively identified, without any chemical separation.

Whole-body monitors

The high gamma efficiencies available with large scintillation phosphors has made it possible to measure directly the presence of very small quantities of radioactivity ingested or absorbed in the human body; this may be accomplished with liquid scintillators or with large NaI crystals. The latter method gives information on the energy in addition to the level of the radiations, and hence is capable of identifying the activities.

A spectacular example of the scintillation counter method of assay is the construction of a liquid scintillator tank containing 530 litres of liquid and viewed by 108 2-in. photomultipliers, which has been constructed (*11*) to study the overall radioactivity of the human body. The tank is shielded with 5 in. lead and the subject is inserted into the central tunnel which is 6 ft long and 18 in. dia. The operating background of the detector when measuring gamma rays from 1–2 MeV energy is 200–400 c/s, but since the sensitivity is so high the body content of K-40 (approx. $5 \times 10^{-4}\mu$c) can be measured to 5% in a 100 second counting time.

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Cross Section by GRACCHUS

THE row in the House of Commons about private manufacture of fuel elements only reflected the general ignorance and confusion that exists on the subject—and not only among MPs. Nevertheless the situation is profoundly unsatisfactory and the Nuclear Installations (Licensing and Insurance) Bill, now in the committee stages, is now a long overdue measure. The fact that Marston Excelsior have for years been assembling enriched fuel plates with Dido-type elements is certainly not news to readers of this magazine and had, I thought, been general knowledge for a long time. Now, ICI produce a brochure in which they briefly mention the fact and before they know what's happened there are questions in the House. As a matter of fact, ICI was the first organization in the country to produce metallic uranium in any quantity, way back in 1942, and this is the first time anyone has complained. It was made perfectly clear by the Prime Minister that Marston merely assemble the plates but the fact of course remains that they handle enriched uranium and it is a matter of some concern that the legal aspects of this are not yet tidied up. They are incidentally not the only company who have to deal with enriched uranium and at present they all operate in an obscure legal fog.

As far as I know there has never been any suggestion that private industry take over the manufacture of fuel elements for the CEGB stations although that could come in time. As a matter of fact the AEA are just beginning to make quite a tidy sum out of this and it seems unlikely that they would willingly give it up. Nevertheless as advanced reactors develop, needing comparatively small amounts of enriched fuel, private industry must be expected to take over some of this work. Indeed Mr. Macmillan said that Rolls-Royce would in fact be making the elements for British submarines. Thus it is essential that a rigorous licensing and inspection system be got ready with no more delay.

The provisions of the Bill are very wide and when it becomes law any nuclear 'installation'—and that doesn't mean just reactors but virtually any place outside the AEA establishments in which fissionable material might happen to be—will have to be licensed and subjected to inspection by the Minister of Power or the Secretary of State for Scotland. How these bodies—particluarly the latter—are going to go about this seems rather a problem. Presumably, at least for a start, they would delegate this function to the AEA who at the moment have a virtual monopoly of this kind of knowhow. It is proposed incidentally that a nuclear site licence will only be granted to a 'body corporate' (e.g. a private or public company) and will not be transferable. Labour efforts to get this limited to statutory undertakings (such as the CEGB) or research organizations were defeated. The Nuclear Installations Bill should certainly have passed through all its stages by the summer recess. This might allow the Act to come into force by the turn of the year.

CHAPELCROSS hardly got the publicity it deserved—it is a fine plant, carried through most expeditiously. The most interesting thing about it I think was the fact that unlike Calder *or* the CEGB stations a firm of consulting engineers was responsible for supervising the construction. This profession is often inclined to be regarded as a back number by many nuclear people and certainly there are only a handful of such firms in this country capable of handling a nuclear power station. Of course the reactors were already designed by the AEA, but this particular firm must have gained invaluable experience in adapting the design to a different site and they are now presumably well equipped to take on a bigger job.

On the occasion of the opening there was once again an outbreak among the newspaper correspondents of the popular pastime 'how many bombs per year?' I do not presume to know how much plutonium goes into a bomb but it is easy enough to make a fair shot at the output of the explosive.

A basic fact of any reactor is that the fission of 1 gram of U-235 produces almost exactly 1 megawatt-day of heat. In fissioning, the neutrons emitted from one U-235 atom produce a certain amount of Pu-239 from the U-238. The amount created varies with the type of reactor but it has been stated publicly on many occasions that in the Calder Hall type, the conversion ratio is about 0·85. Now at full load the reactor heat output is 200 MW, so it burns 200 grams U-235 in a day, at the same time creating 170 grams of Pu-239. Up to this stage we are sure of our facts. Now comes an uncertainty—how many days of full power operation do they get in a year? Remembering that the reactor has to be shut down for fuelling, let us make a guess of 60% load factor—say 220 days. Thus each reactor should produce about 37 kg Pu a year. With four on the line we get 150 kg or about 330 lb a year. Doesn't sound much, does it?

THE Galbraith Hearings—what we've been allowed to hear, that is—have been greeted with floods of relief after what seems like an eternity of natural uranium bread (frightfully good for us of course). Now we're suddenly confronted with a dazzling array of cakes (all more or less home-made, if not all to indigeneous recipes) and the choice is of course terribly difficult. How many can we have? Will they give us indigestion—or worse? Here then is Gracchus' assessment of the selection :

nourishing—the AEA's AGR
fruity—GEC's gas-cooled
spicy—Vicker's steam-cooled
sweet—Hawker Siddeley's OMR
hot—de Havilland's HTGR
smooth—B & W's PWR
tempting—Mitchell's BWR
delicious—AEI/JT's BWR

How will they work out? One must, I feel, qualify for the title 'most stodgy.' Award of this however must await events.

FOR the seventh year the Waverley Gold Medal is being offered together with a prize of £100 for the best essay of about 3000 words on a new scientific project or practical development. Sponsored by *Research* the competition is open to anyone at present engaged in scientific work and entries are due by July 31. I can supply further details to anyone interested.

On Record

PENNEY's TRIUMPH It will now be much easier for the Japanese, Italians, Germans, French and other nations building peaceful atom-power plants to make bombs.—London Daily Express.

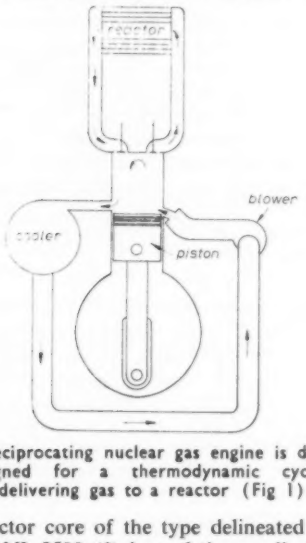
The time has gone when seekers after physical, chemical, or geological truth are popularly regarded as back-room boffins: probably bearded and untidy; possibly only vaguely beneficent, and invariably absent minded.—H.R.H. Princess Margaret.

A new concept in power plants

by A. P. FRAAS, *Oak Ridge National Laboratory*

ASPECTS of power reactor design were reviewed recently in an effort to find a system suitable for marine applications. The requirements of high temperatures and high thermal efficiency, combined with low output shaft speed, smooth and efficient operation over a wide speed range, and the ability to reverse easily and rapidly provided an intriguing suggestion: a reciprocating engine operating on a gas cycle.

A preliminary study indicates that a reciprocating engine coupled to a gas-cooled reactor with a system pressure of around 100 atmospheres will lead to a cycle efficiency of 30% and a unit output equal to or greater than that of modern diesels. Such an engine can be coupled to a gas-cooled



Reciprocating nuclear gas engine is designed for a thermodynamic cycle delivering gas to a reactor (Fig 1)

reactor core of the type delineated in ORNL-2500 (*1*) but of the small size considered in subsequent studies directed at reductions in capital investment (*2*). It has been shown that these small gas-cooled reactors will operate with low enrichments, with a low critical mass, and with a good conversion ratio; they should permit high fuel burnups with low fuel fabrication costs and thus the overall fuel cost will be low. Studies indicate that, for modest power densities, the materials combination chosen leads to a system remarkably good from the hazards standpoint, and hence the extra cost and complexity introduced by hazards considerations appears to be substantially less than for other types of reactor.

The proposed reciprocating nuclear gas engine (Fig. 1) is designed for a thermodynamic cycle in which the gas is compressed and delivered to a reactor. After heating, gas is returned to the cylinder in which it is expanded to do work. At the end of the expansion stroke the piston uncovers ports which permit loop-scavenging of the cylinder by a low-pressure gas system which includes a cooler and a blower to complete the thermodynamic cycle. The piston would approach the top of the cylinder very closely so that the clearance volume would be almost trivial. The exhaust valve would open as the piston approached top dead centre and would close as it reached there. The intake valve would open at top dead centre to admit hot gas and would remain open until the piston had moved part way down in the cylinder (Fig. 2).

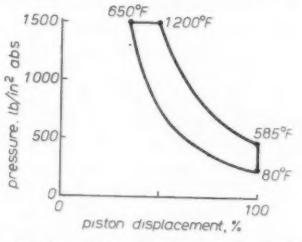
Helium and nitrogen promising

From the materials compatibility standpoint the most promising working fluids for this application are helium and nitrogen. Either can be used with stainless steel, carbon steel, and graphite up to temperatures well above 1500°F. Helium is attractive because its good heat transfer characteristics and high ratio of specific heats makes possible a high thermal efficiency with a volumetric compression ratio of around 3:1.

Nitrogen could be used and a good thermal efficiency obtained with a compression ratio of about 5:1 but, although it has the advantage of low cost, the m.e.p. and hence the output for a given size is about one-third less than for helium. The poorer heat transfer performance of nitrogen would also yield a somewhat lower output from a given size of reactor. Its most important shortcoming relative to helium is that it entails much higher pumping losses in both the high and low pressure circuits.

Because of its ready availability, however, nitrogen was used as a basis for a conceptual study of a plant for the NS *Savannah*.

The reactor design follows closely that of the GCR-2 presented in ORNL-2500. The fuel elements would be the same except that their length would be 24 in. instead of 40 in. The limiting stainless steel capsule temperature would be the same (1500 F) but the much higher heat transfer coefficient available at 1500 lb/in.^{2} permits increasing the gas outlet temperature 100°F. A development programme for these fuel elements is now well underway. Fuelling would be essentially



Idealized cycle operating on helium with a compression ratio of 3 : 1 (Fig 2)

the same as GCR-2 although an additional locking device would be required to hold the fuel element against the accelerations experienced aboard ship. The control rod drive mechanisms would differ from those of the GCR-2 in that a rack-and-pinion drive would be used instead of a winch. Seven control rods would be employed, one in each of the fuel charge tubes. As in the GCR-2 the actuating mechanism would operate at the system pressure to avoid the need for seals.

The Cooper-Bessemer LSV12 diesel was chosen as the basis for the engine. These are currently built for marine applications with two, three, and four engines connected through electric couplings and a reduction gear to a single propeller shaft.

This study, which is more fully reported in the Proceedings of the 1958 Nuclear Merchant Ship Symposium (USAEC), indicates that the total cost of the nuclear power plant, excluding development work on the engine, would be about $M9 which is about 60% of the *Savannah's* pressurized water system.

Some of the problems expected in the development are as follows: engine breathing and leak-tightness, prevention of lubricating oil in the gas circuit, fuel element security against

accelerations, startup and after-heat removal, control—particularly during manoeuvring.

Specifications for the Proposed Nuclear Gas Engine Power Plant—NGE-1

GENERAL	
Shaft horsepower	20/22,000
Reactor power (max.)	60 MW
Overall thermal efficiency	30%
REACTOR	
Fuel element	UO_2 in s.s. capsules
Moderator	Graphite
Lattice pitch	8·0 in.
Core diameter	8·5 ft
Core length	10·0 ft
No. fuel elements	4655 capsules 665 assemblies
No. fuel channels	133
Pressure vessel I.D.	12 ft 8 in.
Pressure vessel thickness	8 in.
Pressure vessel height	23 ft
Shield O.D.	26 ft
Shield height	32 ft
ENGINE	
No. of main propulsion engines	4
Bore	15·5 in.
Stroke	22 in.
No. of cylinders	12 (V)
Speed	335 rev/min
Compression ratio	4·8
Power per engine	7500 b.h.p.
Brake m.e.p.	130 lb/in.^{2}
GAS SYSTEM	
Total gas system volume	1800 ft^3
high pressure system	1200 ft^3
low pressure system	600 ft^3
Gas flow at full power	465 lb/s
Gas temperature, reactor inlet	600°F
Gas temperature, reactor outlet	1100°F
Gas temperature, cooler inlet	470°F
Gas temperature, cooler outlet	90°F
Pressure at cylinder discharge port	1500 lb/in.^{2}
Pressure at cylinder return port	1456 lb/in.^{2}
Pressure at cooler inlet	157 lb/in.^{2}
Pressure at cooler outlet	152 lb/in.^{2}
Pressure at cylinder intake port	165 lb/in.^{2}
Gas density at cylinder discharge port	3·7 lb/ft^3
Gas density at cooler outlet	·723 lb/ft^3

References :

1. *The ORNL Gas Cooled Reactor*, ORNL-2500, March 1958.
2. *Design considerations for high-pressure gas-cooled reactors with small cores*, ORNL-CF-58-7-55, Sep. 1958

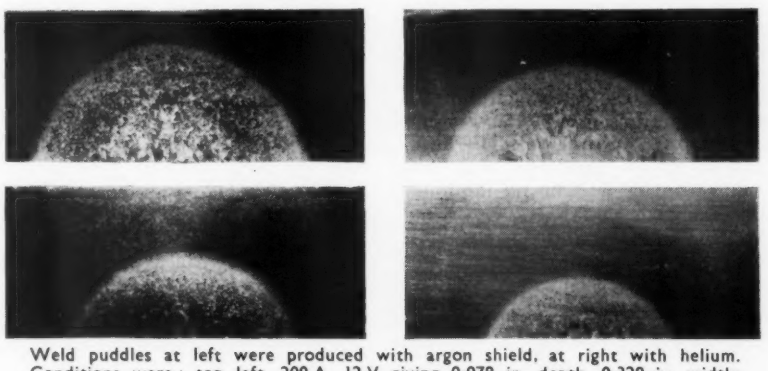
Nuclear Technology | Materials

A comparison of argon and helium welding shields

by J. BARKER, *M. & C. Nuclear Inc.*

THE purpose of this experiment was to determine the differences in weld puddles obtained by helium and argon shielding and to present the results in a usable form.

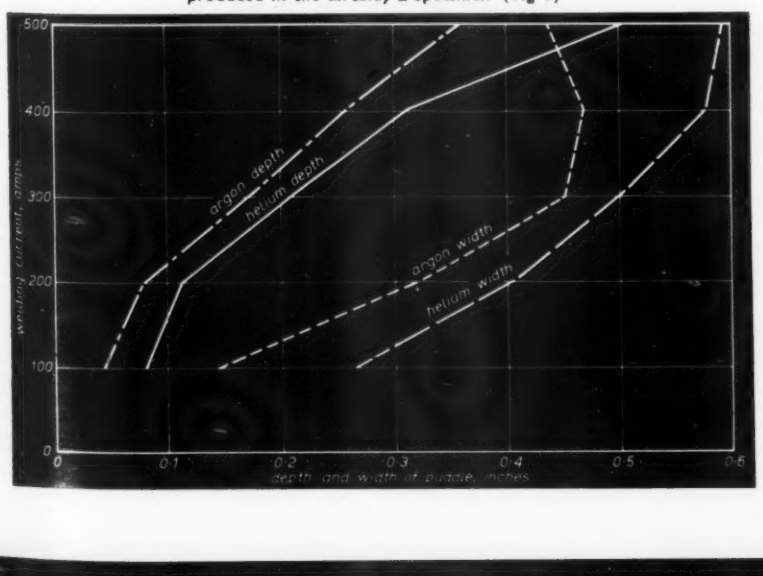
One piece of zircaloy-2, 16 in. × 5 in. × ·500 in. was obtained from scrap. This was sawed into two pieces, each 8 in. long. One piece was placed in a drybox evacuated to less than ·03 microns and then backfilled with helium to ½ in. pressure. Five weld beads were run on the piece at 100, 200, 300, 400 and 500 amps with at least one hour wait between welds. The reference voltage was set at 15 volts and the speed at 8 in. per minute. In all cases, the electrode size was appropriate for the amperage used. For the second piece, the drybox was evacuated to less than ·03 microns and then backfilled to + ½ in. argon. Five more weld beads were run at the same amperages and speed, but in this case, the reference voltage was set at 12 for the arc lengths to be comparable.



Weld puddles at left were produced with argon shield, at right with helium. Conditions were : top left, 200 A, 12 V giving 0·078 in. depth, 0·328 in. width; bottom left, 300 A, 12 V, giving 0·172 in. by 0·453 in.; top right, 200 A, 15 V, giving 0·113 in. by 0·406 in.; bottom right, 300 A, 15 V, giving 0·210 in. by 0·500 in. (Fig 2)

The two specimens were then examined metallographically. Each weld bead was sectioned at right angles to the direction of the weld travel, polished, etched for grain size and then photographed. Measurements of depth and width of weld puddle are probably subject to ±10% error, especially the former which, in some cases, shows very little demarcation between the heat-affected zone and the actual molten metal.

Welding current had a marked effect on the depth and width of weld puddle produced in the zircaloy-2 specimen (Fig 1)



The comparable results are shown in Fig. 1. Note that the depth lines between 200 and 400 amps, for both argon and helium, fall close to a straight line. At 500 amps, the argon line is still straight, but the helium shows much more penetration. This is due to the fact that there is not enough cooling in a ½ in. piece of zircaloy, and with the heat-affected zone all the way through the piece, the arc is able to melt more and penetration goes up rapidly. With a sufficient mass of zircaloy or good copper chills, penetration at 500 amps in helium could be expected to fall at about ·400 in. depth.

The width line on the graph would also fall close to a straight line if the arc voltage control was not used. At the higher amperages, the arc forces

a depression in the molten metal and since arc length is controlled by voltage, the electrode lowers itself into this depression. At 500 amps in argon, the tip of the electrode is estimated to be approximately $\frac{1}{8}$ in. below the flat surface of the work. This means that most of the molten metal is also below the surface and as a result, the apparent puddle width on top of the piece is narrower than might be expected. Trials without arc voltage control have not been made, but it is believed that the puddle width would then fall very close to a straight line both for argon and helium. It should be noted (Fig. 2) that the grain sizes of the helium welds are larger than the argon welds at the same amperage, but for a given penetration, the grain sizes are about equal.

Nuclear Technology Processes

Handling curie levels of beta-gamma active solutions

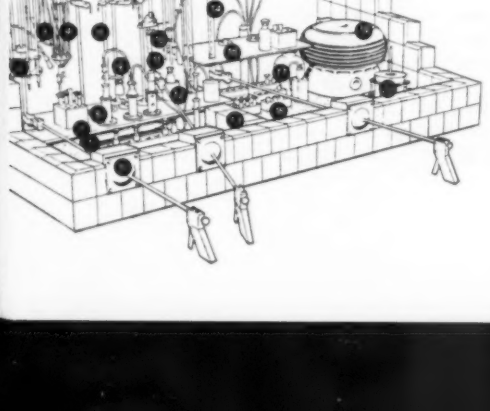
by J. H. MOSS, G. P. KITT and P. E. BROWN, *A.E.R.E., Harwell*

THE WORK described here started with a general commitment to investigate the separation of certain fission products from concentrates containing up to 1 curie activity per millilitre. Suggested processes were finally tested on hundreds of curies of fission products in a large concrete cell. Such work was necessarily slow so, to save time, as much active work as possible was done on the millilitre scale in shielded fume cupboards using equipment designed to be simple, safe and versatile. In this way much valuable information on the suggested processes was obtained relatively very quickly. A full account of the equipment and techniques used in working on the millilitre scale is given in UKAEA report no. AERE C/R 2622. The following is an outline of some of the features.

Three fume cupboards were adapted for experimental work on old (1–8 years) fission product concentrates. The work consisted of general solution chemistry with precipitations and evaporations but did not involve dry solid or volatile active materials. Because of the need for versatility, the apparatus was made as simple as possible which also made for rugged construction (few breakages), rapid manufacture, few handling mistakes, ease of decontamination and cheapness, all of which were desirable. To avoid crowding the working space, apparatus was kept small and solution volumes of 1–40 ml were commonly used, though these volumes could be changed by a factor of ten either way. The small volumes used enabled solutions of relatively high specific activity (up to 2 curies/ml) to be investigated behind a standard 4 in. lead wall. Equipment was designed, as far as possible, for remote replacement so that contaminated apparatus could be removed and new experiments set up quickly.

Working space in the cells was adequate to perform operations one at a time but careful planning was needed to avoid congestion and it was advisable to have adequate storage space for apparatus not in use

1. strip lighting; 2. pipette rack; 3. C7 polythene stopper/glass sockets (all others are C12); 4. liquid feed; 5. clamps and frame; 6. $\frac{1}{4}$ in. tong unit; 7. holding blocks; 8. perspex holders; 9. vial piercing device; 10. active sampling point; 11. stirrer; 12. local shielding of active pot; 13. 4 in. lead wall; 14. Dexion framework; 15. ball and socket joints; 16. perspex shelving; 17. waste disposal; 18. lead shield storage; 19. centrifuge; 20. evaporator



Double containers used

In order to reduce contamination, the standard double container practice was used and all operations were, as far as possible, totally enclosed. Graduated, stoppered centrifuge tubes, which had to be used for centrifuging, were used also wherever possible for experiments; standardization of containers and tops of tubes (C 12 sockets) considerably reduced the amount of apparatus required. Polythene stoppers were regularly used in this work. Apparatus was designed for the addition of reagents, sampling, centrifuging, heating, evaporating, stirring, ion exchange work and analysis. Liquids were moved by remote manual suction through 1·0 mm polythene and stainless steel hypodermic tubing, the depth of liquid take off being controlled by varying the height of the hypodermic tube in the liquid. For transfer of active liquids in and out of the cell polythene tubes were used which could be heat sealed and cut without any escape of activity. Small samples of solution were taken for normal radiochemical analysis but trace levels of inactive components were determined colorimetrically in a remotely controlled Spekker (*1*) on larger samples of solution. This method of analysis was preferred to the preparation of cassettes for spectrographic analysis.

Active waste was normally disposed of in a liquid form, contaminated solid apparatus being washed out before removal from the cell. Solid waste was kept to a minimum and was safely removed in plastic bags using *Cee Vee* reachers.

Three adjacent fume cupboards were used and in each a lead brick wall was built to protect the whole front and some side faces, the depth of each shielded space being about 2 ft 6 in. The centre cupboard was used for highest activity work and had no frontal access but was connected at the rear to the other two cupboards which were used for analysis, and for miscellaneous specialized apparatus. These cupboard had direct access outside through bung ports. The lead walls, normally 4 in. thick except in the analytical cupboard where 2 in. shielding sufficed, contained as standard items (*2*) ball joint units with $\frac{1}{4}$ in. shafted 3 foot tongs (4 per cupboard), 2 in. bung port units for access (4 in. bung port units are much heavier and were not found necessary) and 6 by 6 in. lead-glass window units for viewing. Large tilting mirrors over the top of each cupboard were also used for viewing. Tong change stations were not used due to lack of space and the danger of an active spill if replacement was faulty. Universal tong jaws were used on all tong heads and proved quite satisfactory for the operations undertaken. The lead bricks were effectively protected from contamination by painting thickly with *Bostikote* which gave a more reliable protection than p.v.c. sheeting.

Routine working gave little free activity in the cell. Highly contaminated surfaces arose on solids which had been in contact with active liquids or with spray from these liquids. Apparatus and operations were carefully designed to prevent exposure of these surfaces. Air stirring and bubbling (a potential hazard) was done through a vented filter if more than 1 minute's stirring was required. Operations in

open tubes were avoided as they gave higher contamination levels (10 to 100 times higher for routine operations). In routine working the chief spread of activity was from the tong jaws touching a contaminated object. To counter this p.v.c. jaw gloves were developed which could be readily washed or replaced remotely. These worked well although they were slightly less sensitive than ungloved jaws. Attempts to fit p.v.c. gloves on *Cee Vee* reachers were less successful—these were protected by a thin film of *Bostikote*.

Possible escape of activity from the cell by various routes had to be prevented. The lead walls were heavily 'bostikoted' inside and out and no activity came through them. Care was taken to avoid touching the bung ports when posting out contaminated objects. The suck lines gave no trouble except when a powerful continuous suck was applied with a vacuum pump. Activity was then found in the pump oil—this was afterwards avoided by limiting the pumping rate and using an efficient scrubbing system. Activity was never observed in the air outside the cell showing the draught was an adequate protection of the gap at the top of the lead wall. The tong shafts caused most trouble, especially once when spray from a spill fell on the tongs. External tong gloves were fitted as the cell wall had already been built.

Radiation shielding was adequate and 10 curies of caesium were held safety in the cell. There was no trouble with scattered radiation and even with a removed bung port the zone above tolerance radiation did not usually extend more than 6 in. from the port.

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2. A. B. Ritchie and R. A. G. Welcher, *A review of remote handling equipment available at AERE*, Glove Boxes and Shielded Cells. London: 1958, Butterworth.

Nuclear Technology Radiation

Calibration of neutron sources

Methods used at the National Bureau of Standards

IN the late 1940's, two nearly identical radium-beryllium neutron sources were constructed by the National Bureau of Standards in Washington to serve as standards of neutron source strength. Each source consists of a capsule of 1g of radium in the centre of a beryllium sphere, 4 cm in diameter. One source, NBS-1, serves as the National Neutron Standard: the second NBS-2, is loaned to other laboratories to intercompare sources throughout the world. It was recently sent to England and to Sweden for international intercomparisons.

In the past, most national standard neutron sources have been radium-beryllium (α,n) sources, made by mixing a radium-containing powder with beryllium powder. Although these sources have high neutron yields, they are not completely satisfactory because the neutron strength increases with time as radium decays to polonium. Any change in state of the mixed powders can lead to a change in neutron emission rate, which is, of course, undesirable in a standard source. The capsule-in-sphere radium beryllium (γ,n) source overcomes this problem as neutrons are produced only by the gamma-rays from radium acting on the beryllium in the spherical shell.

While these photoneutron sources are very well suited for standards, they are inconvenient to work with in some laboratory situations because of large gamma-ray emission. More acceptable laboratory standard sources are plutonium-beryllium (α,n) sources, which have been made available by the Atomic Energy Commission. This type of source, which provides low gamma-ray emission and long half-life, is sometimes used as a working standard at the Bureau.

The NBS standard neutron sources have been intercompared, either directly or indirectly, with the national standard neutron sources of all countries known to maintain sources including the USSR. All of these sources are in agreement to within about 2% of the international mean value.

Calibration methods

The National Neutron Source has been calibrated absolutely in two different ways. The first, and most tedious, method involved the measurement of a thermal-neutron density in a water tank surrounding the source. In the idealized situation, the water tank is large enough so that it can be assumed no neutrons escape. Each neutron from the source must therefore appear as a thermal neutron somewhere in the tank. By integrating the thermal-neutron density—measured by its effect on a foil calibrated in a known thermal-neutron density—the neutron emission rate of the source is obtained.

NBS neutron standard consists of a solid beryllium sphere, 4 cm dia., with a radium capsule enclosed at its geometrical centre

The second type of absolute measurement of neutron source strength involves activating a water bath containing manganese sulphate. Neutrons from the source are slowed down in the bath and are captured finally either by manganese atoms or hydrogen atoms. The number of manganese atoms activated is measured by a method which amounts to absolute counting of the induced beta activity of the manganese. The fraction of neutrons lost to hydrogen is estimated either from the measured manganese and hydrogen thermal-neutron absorption (cross sections) or by changing the concentration of manganese in the bath and comparing activations.

The standard thermal-neutron flux geometry used for calibrating neutron fluxes consists of two symmetrically placed radium alpha-beryllium sources surrounded by lead and paraffin with a carbon-shielded detector slot in between. The neutrons are slowed down by the shielding materials before reaching the slot. The thermal-neutron flux in this slot has been calibrated by absolute counting of the boron-10 (n,α) reaction, the thermal-neutron cross section for this reaction being well known. From observations of the count rate in a proportional counter or pulse ionization chamber containing a known amount of B-10, the thermal-neutron flux can be determined. The NBS standard thermal-neutron flux is known to within about 2%. Investigations are presently under way aimed at an independent calibration of this flux by beta-gamma coincidence counting of gold-198. Unknown fluxes are calibrated against the standard by activating foils in both.

Pressure vessel fabrication

new heavy engineering shop at Derby

CONSTRUCTION of the four heat exchangers for the Advanced Gas Cooled Reactor (AGR) to be built at Windscale by the UKAEA is now well under way at the Derby works of International Combustion Ltd., who obtained this £500,000 contract last year against stiff competitive tendering. The work is being carried out mainly in the new Heavy Engineering Shop which was opened on April 24 by Lord Mills, Minister of Power.

Planned long before the AGR contract was received, the new shop covers 68,250 ft² and is particularly well-equipped with the latest in heavy plate-working machinery. Delivery of the AGR exchangers is required by the end of 1959 and to achieve this, the shop construction schedule had to be advanced by six months. In addition, a separate 'clean-conditions' building was required and this is now nearing completion. The firm are thus confident that with these production facilities, the AGR delivery dates will be fully met.

During a recent visit to the plant, we were shown the AGR exchanger production line by Mr R. Burleigh, a director of IC Ltd. and Works Manager at Derby. The shells are 11 ft 6 in. dia, and about 80 ft high. The strakes are formed from a single 1 7/16 in. plate except for the lowest, support, strake which is up to 2½ in. It was an AEA requirement, in view of possible modifications after operation, that the shells be in three sections joined by bolted circumferential flanges, seal-welded at site. The three component parts, reading upwards, consist of self-contained economizer, evaporator and superheater sections. This requirement gave the opportunity for completely tubing the exchangers at the works, since the weight of the sections is within the road transport limits. This is a new departure in power station construction and is possible of course only due to the relatively small size of the exchangers compared with those at the first round power stations.

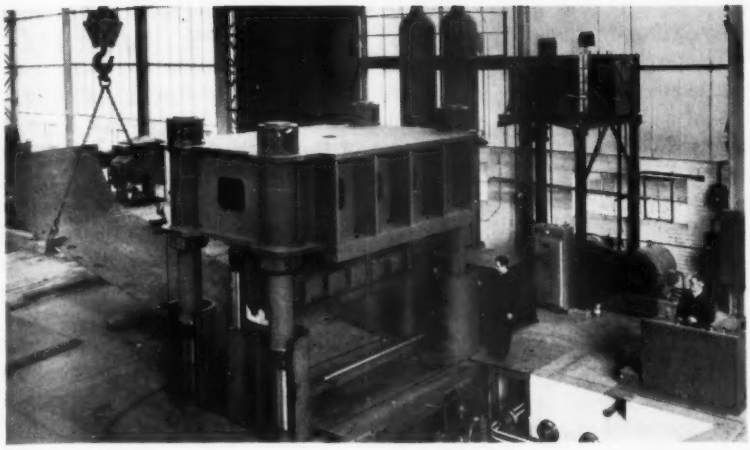
Plates are first examined ultrasonically and then cut to size on a flame planer. Weld edge preparation of J-form is then done on a Hugh Smith machine capable of handling 35 ft-long plates. Rolling is done in two stages. Firstly the plate ends are given the correct curvature on a Fielding and Platt downstroking four-column 2000-ton press using shaped forms. This machine can also be used for hot pressing of dished ends and petal plates, and a plate heating furnace is conveniently located a few yards away. The AGR exchanger ends are however rotary spun by subcontract and not pressed at Derby.

Rolling of the plates is now completed on a Fielding and Platt 10-ft vertical plate bending press of 3000 tons capacity. This machine can handle cold plate of from 3 to 4 in. depending on the curvature required. There is also similar machine capable of handling plates 15 ft wide. The next step in heat exchanger manufacture is closing the longitudinal seam and this is done by the Unionmelt process using a Quasi-Arc boom welder (a similar machine was fully described in our December 1958 issue). Strakes are welded together circumferentially and then the flanges are fitted. For stress-relieving, the new shop houses two Dowson and Mason gas-fired furnaces of different sizes.

Tube elements are fabricated in another shop. Economizer and evaporator banks are formed from Tube Product's edge-welded helically finned tubing, while the superheater sections are of chrome-molybdenum plain tubing. Return bends are hand-welded using International Combustion's broken arc technique. There are some 23,000 of these welds in the contract and every one is subject to a radiographic inspection from either side, with complete records kept. Unlike the Calder Hall exchangers and those in the CEGB power stations, the AGR ones will only have headers between sections, thus drastically reducing the number of thermal sleeves to be fitted.

As mentioned previously, the tube banks will be fitted in the new clean conditions shop. The empty shell sec-

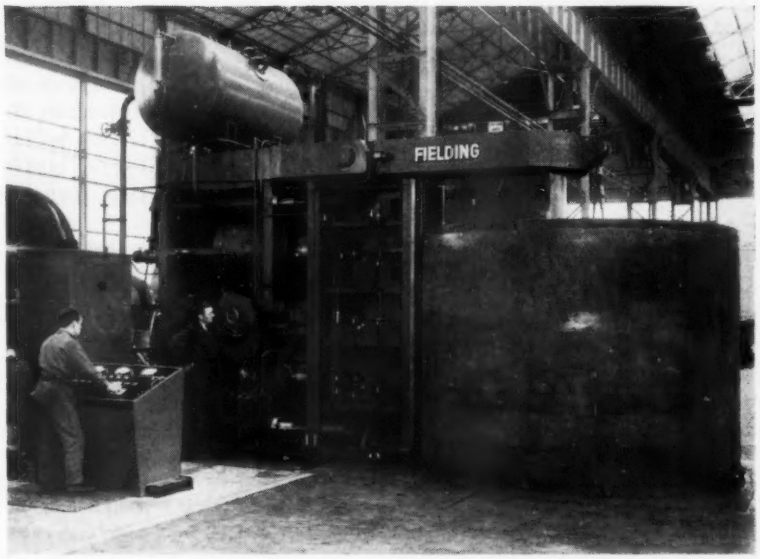
General view of the new Heavy Engineering Shop shows AGR heat exchangers sections in various stages of manufacture. Note top dome on the left complete with flange for bolting to the centre section



The ends of the AGR heat exchanger plates are first formed in a 2000-ton down-stroking press. The plates are $1\frac{7}{16}$ in. thick

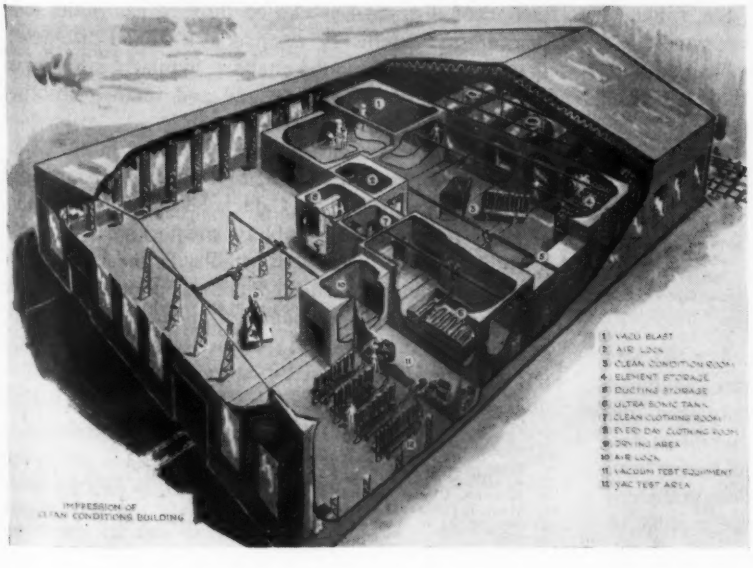
tions will be sealed at one end and the open end bolted round a circular opening in the wall. Working inside on the clean side of an air lock system the inside of the shell will then be cleaned using a Vacu-Blast Major machine. Meanwhile the assembled tube sections will have also been vacuum blasted. They will then be cleaned inside and out in an ultrasonic bath of trichlorethylene. The final stage will be a comprehensive leak test schedule. After assembly of the elements in the shells they will be sealed off ready for transport to the site where, before unsealing, further clean conditions will be established. One of the company's problems, Mr Burleigh told us, was that of educating the men to the quite unfamiliar techniques of clean conditions working and this is being done by lectures and demonstrations on the importance of achieving the standards of cleanliness required.

The new heavy engineering shop is the largest single-extension ever built at the Derby works and is designed to widen greatly the scope of the company. As a constituent company of the Atomic Power Construction group, International Combustion are keenly interested in the result of the competition for the Central Electricity Generating Board's 500 MW Trawsfynnyd power station. If APC obtain this contract the heat exchangers will be made here at Derby. To provide sufficient headroom for such very large shells (about 18 ft dia) the centre bay of the shop contains a welding pit 150 ft long by 25 ft wide by 12 ft deep.



Forming of the AGR heat exchanger plates is completed on a 3000-ton vertical machine. The next stage in manufacture in the longitudinal seam weld

Artist's impression of the clean conditions building at International Combustion's Derby works shows how the AGR heat exchanger sections will be cleaned and fitted with the extended surface tube banks



Work on the new shop began in January 1958 and the building was completed in September. Then began the job of preparing foundations for the heavy machinery and installing it. The building is 350 ft long and consists of a centre 75 ft bay with two flanking 65 ft bays. Each bay is served by two gantry cranes, the largest of 50 tons capacity. A feature of the construction is the large amount of daylight from the double glazing.

With this new facility, International Combustion should be well placed to handle any foreseeable nuclear contracts.

continued from p. 97

For $3.10^{-3} < \triangle k_T < 8.10^{-3}$ the instability is oscillatory and it may be concluded that the effect of xenon plays a crucial part in the reactor's kinetic behaviour. For $\triangle k_T > 8.10^{-3}$ the time constant is purely real and the behaviour is thus dominated by the temperature effect. For a graphite power reactor at high irradiation it seems likely that a perturbation time constant of the order of 20 minutes may be anticipated in the first azimuthal mode.

For higher modes, the picture is basically similar to that given in Figure 3 but with a suitable shift of scale.

Axial instability

So far in our discussion of spatial instabilities, we have restricted consideration to radial and azimuthal modes. The problem of deciding whether perturbations entering through modes such as the first axial mode

$$f_4 \equiv f_{120} = J_0\left(j_0^{1)} \frac{r}{R_0}\right) \sin \frac{2\pi z}{L_0}$$

lead to instability or not is more difficult than the corresponding problem in the (r, θ) plane, due to essentially axial effects such as coolant flow and control rod positioning.

It may be observed, however, that the transport of heat up the reactor by the coolant is a stabilizing factor, for a fall in the neutron flux in the top half of the core is compensated by an increased flow of heat from the lower half where the flux has risen. It may be shown that the part played by the fuel and moderator axial temperature distribution depends upon the amount by which they differ from the axial distribution of coolant temperature. For an axially uniform core the terms T_u^* and T_g^* occurring in the criteria for radial and azimuthal instability are, for axial effects, replaced by $\triangle T_u^*$ and $\triangle T_g^*$, where $\triangle$ indicates the mean difference between material and coolant temperature at the core mid-plane. The magnitude of the temperature effect thus depends upon the efficiency of heat transfer to the coolant. In gas-cooled graphite reactors the value of $\triangle T_g^*$ is small and the temperature contribution to the instability criterion correspondingly slight. In addition, the current civil reactor cores tend to have a rather squat geometry, so that axial leakage terms

$$\triangle k_D = \frac{M^2\pi^2}{L_0^2}\,(l^2-1)$$

are large.

On the whole, it seems likely that axial instability will not be present in a typical civil reactor.

Design of control system

We have seen that typical graphite power reactors are unstable to fundamental, first azimuthal and possibly higher, modes of disturbance. Generally speaking, components of all these modes will be present in any perturbation to the neutron flux, which could arise from a definite fault condition or from a random statistical change, and thus the control system must be capable of dealing with the spatial as well as fundamental type of instability.

For the latter, absorber adjustment anywhere in the reactor core will suffice, provided that it is sufficiently rapid to be able to deal with a perturbation doubling time of the order of two or three minutes. But to deal with an instability in the f_3 mode for example, it is necessary to introduce absorber into the region of increasing flux and withdraw absorber from the region of decreasing flux, albeit on a longer time scale. If the nodal plane of the mode were fixed and defined, then a control rod system in which rod movements were equal and opposite in opposite halves of the reactor would control the mode. This could be combined with a fundamental control system by having effectively independent control and instrumentation for each half of the reactor.

However, the position of the nodal plane of the f_3 mode will depend on the nature of the perturbation. Thus in order to allow for all positions of this nodal plane it is necessary to have several control systems each acting in a small sector region of the reactor. This is even more necessary if higher azimuthal harmonics require control. In typical civil power reactors about eight such sectorial control regions are required.

Radial instability

For control against radial mode instability, e.g. f_2 mode, it is necessary to provide independently acting control within and outside some given radius (see Figure 1). This could be combined with a sectorial system by introducing a controlled absorber near the core axis and ensuring that the sectorial control acts sufficiently close to the core perimeter. Clearly if the fundamental mode can be controlled, so can the flux shape, provided a sufficient number of independent control regions with adequate capacity is available. For control against possible axial instability (e.g. f_4 mode), somewhat different detailed problems are posed. In the azimuthal cases detection of disturbances can be through gas outlet temperature measurements, whereas in the axial case detection is required *along* the channel. Similarly in the axial case it must be possible to add and remove absorber along the length of the reactor.

As yet, no experience has been obtained in this country of the operation of reactors which would exhibit spatial instabilities. The Calder Hall reactors, whilst showing fundamental instability, are too small and too lowly rated to be spatially unstable. In the US side-to-side oscillations in neutron flux with periods of about 24 hours have been encountered in the PWR at Shippingport (*5*). It is reported that the technique of correcting the flux distribution by control rod positioning is quite satisfactory.

References :

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2. Randall, D. and St. John, D. S. *Nucleonics* 1958, *16* (March) p 82
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4. Syrett, J. J. NUCLEAR POWER 1959 *4* (April) p 37
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New Product Survey

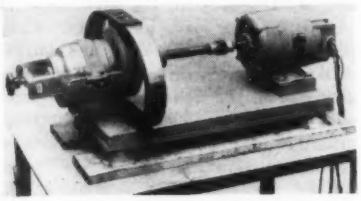
PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

POWDER METALLURGY

new type ball mill

Apex Construction have recently extended their range of vibratory ball mills. Ten models are now available with working capacities from 0·5 to 250 litres.

The Apex Vibratory Ball Mill No. 163 operates on a new principle by which the mill, instead of rotating to cause the balls to cascade, are non-revolving and



The small Apex Mill illustrates the principle. The pot is supported on springs and is caused to vibrate through an out-of-balance mechanism

subjected to a vibratory motion. As the frequency of vibration is high, the balls rapidly subject the material to impacts and at the same time rotate in a circular motion. As a result of this novel principle, materials can be pulverized to a 1 micron size, size reduction is more rapid, and materials which previously resisted disintegration down to impalpable sizes are now capable of such size reduction. At any stage of the size reduction the range of particle size is small and there is an absence of excessive quantities of fine material which cushion the impact of the balls and material and cause wastage of power. Resulting from these characteristics the mill can dispense with screening or air sizing of the product as there are never any particles much larger than the average of the whole batch.

The smaller sizes normally consist of cylindrical pots but the larger sizes use troughs closed with lids. In the smaller sizes the pot is either porcelain or stainless steel; in the larger sizes it is mild or stainless steel. Rubber lined vessels are also available and the larger sizes can be water-cooled. Balls are either porcelain or non-corrodible steel.

Tick **No 208** on reply card

THERMONUCLEAR

stainless bellows for Zeta 1A

One of the main modifications to Harwell's toroidal thermonuclear pinch apparatus Zeta has been the fitting of a continuous stainless steel liner system. Details of the modification were disclosed to the Institution of Electrical Engineers' recent convention on thermonuclear processes.

In the original Zeta, the life of the torus liner was limited by arcing and unstabilized discharge. Other materials were considered but stainless steel was selected as it requires a shorter conditioning period and has a reduced tendency to arc. The problem remained of obtaining a sufficient resistance in a stainless steel liner.

The solution found by Harwell scientists in collaboration with the Bellows Division of Teddington Aircraft Controls was to corrugate the stainless steel tube in thirty-six separate sections of wall thickness ·017 in. using 2½ convolutions per inch, each being 0·7 in. deep. This operation used forming and welding techniques developed for the construction of bellows pipe expansion joints.

This liner system has a 38 in. bore and a main toroidal path length of only 36 ft but produces a resistance of 0·02 ohms. The inside of the completed liner had to be chemically clean, and a heavy oxide coating was required on the outside to provide a high degree of heat radiation to the torus body which was water cooled. An illustration of the lining appears in the article by Dr. Robson in this issue.

Tick **No 209** on reply card

GAMMA SPECTROSCOPY

20th Century's new tube

A new proportional counter from 20th Century, type PX 115, is a high-resolution tube originally developed for the gamma-ray spectrometer. The energy resolution of a proportional counter below 100 keV is better than that of a scintillation counter and its employment extends the range of scintillation gamma-ray spectrometers to 20 keV. Gamma-ray spectrometers are widely employed in the analysis of spectra such as that from fission products and the high resolution of the proportional counter is particularly useful in interpreting the complex spectra at low energies.

The counter is 2½ in. in diameter with an overall length of 16 in. It has a gas filling of a mixture of highly purified xenon-methane at a pressure of 2 atmospheres absolute and the operating voltage range is between 3500 and 4200

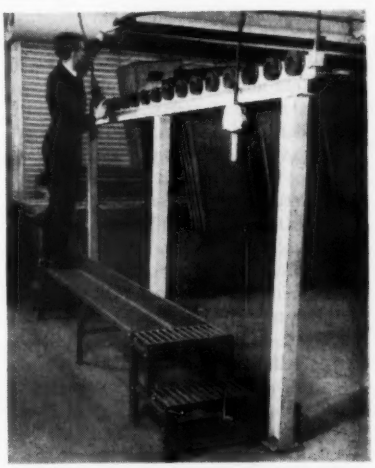
Measurements of the energy resolution have been made using an americium-241 source which emits gammas of 59·4 keV. The best resolution which has so far been obtained with these counters is 5·6%. Over the operating range, the gas multiplication factor is 60 V/dB.

Tick **No 210** on reply card

GRID FLOORING

extension to Dexion range

A new multi-purpose grid that can be used to construct anything from industrial platforms and mobile stairs to car ramps and trolleys, has recently been introduced by Dexion Ltd. Available in two sizes and a standard width, it can be quickly bolted together with fixing



The Dexion grid is used here with standard slotted angles to build a working platform

plates and standard Dexion nuts and bolts to suit almost any purpose where a grid work or flooring is needed in any industry.

The grid is available in 9 in. widths, and in standard lengths of 4 ft 6 in. and 6 ft only. Non-standard lengths in multiples of 1½ in. are available in minimum quantities of 12.

Tick **No 211** on reply card

NEUTRON SHIELDING

wood's new use

A densified laminated wood made from beech veneers interleaved with glue film and compressed under great heat and pressure, known as *Jabroc N*, is available in densities from 84 lb/ft³ upwards, the higher density materials being loaded with additives such as boron carbide or rare earths. At a density of 84 lb/ft³ it

gives the following elemental composition: Hydrogen, 6·06%; Carbon, 46·93%; Nitrogen, 0·11%; Relaxation length for fast neutrons, 7·8 cm.

The primary function of Jabroc N is to provide a biological shield by reducing fast neutrons to thermal energies and the following table gives an approximate idea of the relaxation length of the material for fast neutron and radiation compared with other materials.

	Relaxation Length cm
Water	10
Graphite	9
Aluminium	10
Barium base cement	8
Iron base cement	6·3
Iron	6
Lead	9
Jabroc N	7·8

As the hydrogen content of Jabroc N is more than 6% it need be only half the thickness of natural wood to offer an equivalent shielding protection. Also, in the event of a serious fire, the charred densified wood shield may be expected to retain much of its shielding efficiency whereas, under similar circumstances, a concrete shielding would suffer badly and might disintegrate. Concrete, being a much heavier material, requires much more elaborate and expensive mechanical support and is especially cumbersome to handle where movable shielding is required (e.g. refueller and element road transport coffins).

Jabroc N cannot be used in the interior of a reactor as, quite apart from the temperature considerations, the effect of the extremely high neutron flux very quickly reduces the mechanical properties of cellulose-base materials.

Boards of Jabroc N can be pressed in one piece up to thicknesses of 4 in.; greater thicknesses are available by bonding together boards of various thicknesses with synthetic resins. The material is made by Permali Ltd at Gloucester where there is a total press capacity of over 24,000 tons and probably the largest design and machining resources in Europe devoted to the manufacture and assembly of components and large fabricated structures in plastic laminate materials.

Although the applications are in no way comparable, it is perhaps interesting to note that Permali have supplied many tons of laminated structures and components in densified wood and other laminated plastic materials for Zeta and other experimental thermonuclear fusion apparatus.

Tick No 212 on reply card

BOREHOLE LOGGING
portable exploration gear

For location, estimation and control of radioactive minerals down to 1100 ft, Hendrey Relay's Borehole Logging Equipment, Type 1417A, is capable of providing a permanent record of gamma flux in boreholes over 1 in. dia.

Using the Hendrey borehole logger a UKAEA survey team working near Salisbury, S. Rhodesia, change the probe unit. Winch on the left, measuring head on the right

The equipment consists of a tripod-mounted winch carrying the stranded single-core, double-wire armoured cable, the electrical connexions being brought out through slip rings. The drum is worked manually. The measuring head, which stands on four legs, contains a guide pulley over which the cable from the winch passes into the borehole, a revolution counter which measures the amount run out and a spark recorder giving the gamma plot.

Two interchangeable probes are used: a ¾ in. dia unit containing a gamma-sensitive geiger counter type MG10H or a 1⅛ in. dia unit with a type G24H tube which has a sensitivity about 3·7 times that of the lower sensitivity tube.

The probe output is taken to a Field Ratemeter Type 1368A which supplies the spark recorder. Power is supplied from a 4-cell Nife accumulator, giving about 20–25 hours of operation. The equipment is fully portable by two men.

Tick No 213 on reply card

HIGH SPEED COUNTING
Mullard trochotron tube

Mullard Limited have announced the introduction of a trochotron high-speed decimal stepping tube, for use as a counter or selector at speeds up to 1 Mc/s. The tube, called type ET51, is switched by a negative signal, and provides a constant-current output of 5·5 mA —sufficient to drive a cold cathode decimal indicator (such as the Mullard Z503M) and compatible with the input requirements of direct read-out digital indicators.

Its chief uses will be in nucleonic scalers, decimal computing equipment and electronic switching circuits. In these and similar applications, one ET51 with its relatively simple circuitry can replace a number of conventional valves or transistors and their associated components.

The trochotron is a vacuum device which makes use of crossed electric and magnetic fields to form a beam of electrons between a thermionic cathode and any of ten groups of three electrodes mounted radially about the cathode. The electric field is provided by the inter-electrode potentials within the tube and the magnetic field by a cylindrical permanent magnet fitted externally around the glass envelope.

Each group of electrodes consists of a spade, which forms and locks the beam in position; a target, which makes the beam available as a constant current output; and a grid, for switching the beam from one spade to the next. When power is first applied, all spades will be equally positive with respect to cathode and, due to the action of the magnetic field in preventing electrons reaching the electrode-groups, the tube will be in a 'cut-off' condition, with no beam formed. However, if the potential of any

Mullard's ET51 is mounted on a 26-pin base comprising ten connexions each for spades and targets, 2 grid connexions, and heater and cathode connexions. It has an overall seated height of 3·3 in. and an overall diameter of 1·74 in. including the magnet and special protective caps

spade is reduced, by means of a high-speed pulse or a d.c. voltage, the beam will form on the electrode group associated with that spade, and an output will appear on the corresponding target.

Once formed the beam is held in this position by a combination of the spade series resistance and spade current until it is stepped to the next position by lowering the voltage on the associated switching grid.

Since only the grid in its immediate vicinity will affect the beam, the grids are connected internally in two groups: the odd-numbered grids in one, the even-numbered in the other. This makes it possible to use a d.c. input for switching and still obtain single position stepping, thus avoiding the necessity for a pulse of critical width.

The output characteristic of the tro-

chotron is similar to that of a pentode valve, and in the ET51 over 80% of the beam current appears in the output, the remainder being used to form and lock the beam.

Tick **No 214** on reply card

LEAK DETECTOR

portable mass spectrometer

The new 20th Century mass spectrometer leak detector is a completely self-contained portable instrument which consists of a vacuum system of high pumping speed in which are incorporated the mass spectrometer covering the range of an ionization gauge and Pirani gauge. The system is so designed that components can be directly pumped and leak tested on the apparatus; the combination of Pirani gauge, ionization gauge and mass spectrometer covering the range of leaks from tens of lusecs to 10^{-7} lusecs.

The instrument consists of a miniature 180° mass spectrometer which can be tuned to mass numbers up to 40. The sensitivity of this device is highest at the lowest mass numbers and the use of hydrogen and helium as the probe gases give the highest sensitivity. Using hydrogen, leaks of the order of 10^{-6} lusecs can be detected; with helium, 10^{-7} lusecs is the minimum detectable leak rate of the mass spectrometer ion current.

Tick **No 215** on reply card

JASON REACTORS

range of types now offered

We have recently received from the Hawker Siddeley Nuclear Power Co further details of their Jason research reactor which was described and illustrated in our March 1959 issue.

The reactor can be supplied in several forms but the core components and internal and external reflectors are identical in all cases so that a purchaser of reactor 1 can extend the reactor facilities and power as his requirements demand. The following are the various forms of Jason:

1. A reactor of 1 to 100 watts, having five irradiation ports in the central thermal column and beam holes externally as required by the client. This is ideally suited for driving internal exponential experiments, oscillator experiments, production of short-lived isotopes and activation analysis. Maximum thermal flux is between $1{\cdot}5 \times 10^7$ to $1{\cdot}5 \times 10^9$, depending on reactor power.

2. A reactor of 1 to 10 kW, having internal and external thermal columns and two beam holes giving a total of 21 irradiation ports. This reactor increases the quantity and extends the range of analyses, etc. which can be performed with the reactor 1.

3. The standard 10 kW (continuous) reactor with internal and external thermal column and a shield tank, as described in NUCLEAR POWER.

4. A 10 kW (continuous) Jason with one internal and two external thermal columns. This can be used for driving two external exponential experiments or for applications where there is a requirement for a large irradiation volume for activation analysis, isotope production or oil, grease and plastic irradiations, etc.

5. Jason can be provided with a 10 in. beam hole for neutron therapy studies giving an average thermal flux of 8×10^8 across the beam hole with the reactor operating at 10 kW. Such a reactor would normally be provided with internal and one or two external thermal columns.

A zone of higher flux can be incorporated in the reactor by the installation of a central heavy water irradiation space. This increases the available thermal flux at any given power by a factor of 1·5 to 2 and offers a region of highly thermalized flux. These reactors may also be operated for limited periods at power in excess of the continuous rating, and the firm say they do not consider 10 kW as the maximum output.

Tick **No 216** on reply card

GAMMA RADIOGRAPHY

powerful new MV unit

Newton Victor Ltd, Metropolitan-Vickers' X-Ray Department, recently supplied to Whessoe Ltd a 1500-curie cobalt-60 container, believed to be the most powerful in industrial use in the world. The container was first taken to the AERE, Harwell, for the fitting of the 60 source. From there it was transported by road to Whessoe's Darlington works where it is housed in a specially constructed concrete building. It is used for radiographic examination of welded seams in steel plate up to 5 inches thick.

The protective container is housed in a steel cylinder which can be rolled on its heavy steel end-flanges over rough ground. A steel supporting fork is provided for slinging the unit from a crane or, with the angulating gear disengaged, for hauling the equipment up a loading ramp on to a vehicle. A worm wheel drive fitted to the fork is used to angulate the container, and thereby the beam of radiation, through 350°. Thus, when supported by a crane or other suitable mounting, the container can be rotated about both horizontal and vertical axes and this is of particular value in the examination of spherical and cylindrical pressure vessels.

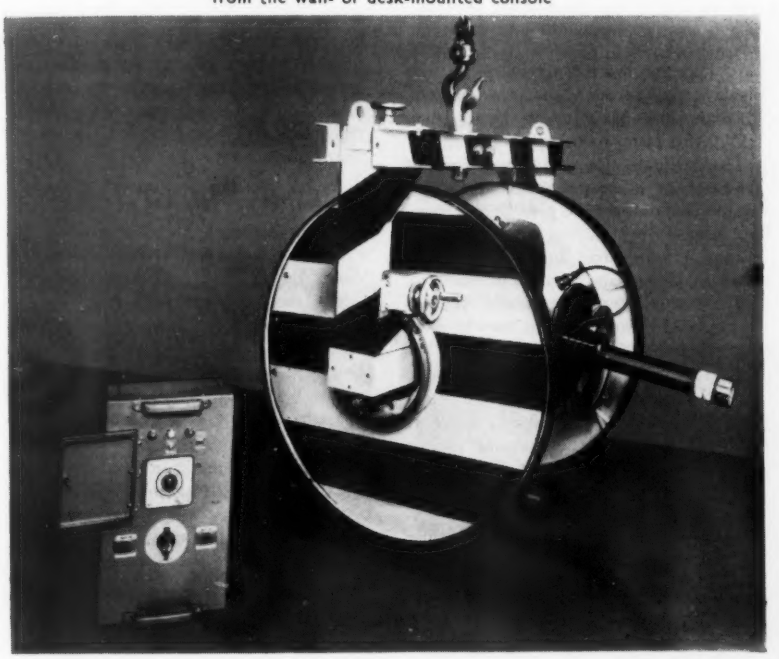
The cobalt source is housed in a lead and heavy-alloy protective container thick enough to reduce the intensity of the radiation at the surface of 6·25 mr/h with a source of 1500 c.

Interchangeable diaphragms of tungsten copper alloy provide a beam of radiation 6 in. or 12 in. wide by 5 ft long at a distance of 12 ft from the source.

During the setting up, a powerful light projector is used to indicate the position of the beam on the specimen at distances up to 20 ft. The light, in the form of a cross, indicates the exact position of the centre of the beam of gamma radiation.

Having positioned the container and adjusted the beam to the desired part of the welded structure, the operator fixes the film or cassette on the remote side and then returns to the remote control console, which may be 100 ft or more away. Alternatively, a concrete wall

Built by Metrovick for Whessoe, this 1500 curie cobalt container will be used for weld examination in pressure vessels. Operation is by complete remote control from the wall- or desk-mounted console



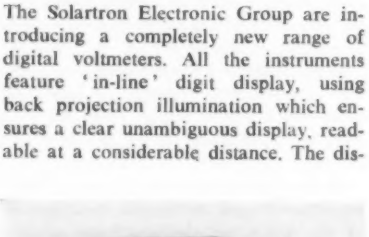
from 9 in. to 36 in. thick may be used to provide the requisite protection. On reaching the control the operator sets the exposure timer and presses a button which brings the source from the 'protected' to the 'exposure' position. At the end of the pre-set period the source is automatically brought back to the 'protected' position; this also happens if at any time the electricity supply is interrupted. Additional signals and interlocking relays to prevent unauthorized entry to the exposure area can be easily connected to the control. Operators can, therefore, work continuously with this container without any risk of receiving an excessive dose of radiation.

Tick **No 217** on reply card

DIGITAL VOLTMETERS

new Solartron range

The Solartron Electronic Group are introducing a completely new range of digital voltmeters. All the instruments feature 'in-line' digit display, using back projection illumination which ensures a clear unambiguous display, readable at a considerable distance. The display may be located remotely, or two displays may be operated from one unit. The absolute accuracy is better than 0·1% short term, or 0·25% long term.



The new Solartron voltmeters are transistorized. This four-window model, LM902, has an accuracy of 0·1% on five ranges and a variable dead-time control for stabilizing the reading on fluctuating inputs

To facilitate parallel operation of print-out or other permanent recording equipment, outputs are provided of decimal coded information which, at any instant, is equivalent to the value indicated by the display.

The LM901 digital voltmeter, for example, will measure up to 99·9 V positive or negative d.c., in three ranges: An 'add 10' facility extends this full-scale reading to 109·9 V. Under normal operating conditions it continuously monitors the applied voltage, but a 'sample' mode is provided which allows a front panel push-button or external relay contacts to give controlled 'lock-out.' This is particularly useful for periodically sampling the instantaneous value of rapidly varying signals which, in the LM901, will normally give a recycling display.

Because the readings obtained are completely unambiguous and of constant accuracy without re-adjustment, these instruments are suitable for use by unskilled or semi-skilled personnel—since the problems of conventional meters such as mis-reading, parallax and statically or magnetically induced false readings are completely overcome.

Tick **No 218** on reply card

TRIGA REACTORS

continuous power increased

We understand from General Atomics that both the Triga I (above ground) and Triga II (below ground) laboratory reactors, which were described in NUCLEAR POWER in our March 1959 issue, are now capable of continuous operation at power levels of 100 kW and above using only natural convection. For round-the-clock operation however over prolonged periods a heat exchange system is employed to maintain the tank water at a reasonable level.

Our description of Triga was for operation at 10 kW: the increase to 100 kW therefore puts up the flux by an order of magnitude to 4×10^{12}. The temperature coefficient at the new power is $1{\cdot}3 \times 10^{-4}$/°C compared with 8×10^{-3} and the excess reactivity 1·6% compared with 0·7%.

Modifications have also been made to the drive mechanisms. The boron carbide control rods are now operated not by stainless steel cables and winches but by solid rods with magnetic release gear at the upper end.

Tick **No 219** on reply card

IN BRIEF

Pulse analyser. A 256-channel unit from Technical Measurement Corporation, North Haven, Connecticut, is contained in a cabinet only 8¾ in. high. It features interchangeable plug-in logic units for pulse height analysis, neutron time-of-flight studies and counting as a function of time. Transistors and printed circuits are used throughout, the display being a 3 in. CRT.

Tick **No 220** on reply card

Flow indicator. An inexpensive and even more compact version of the *Telicator* liquid flow indicator has been added to the range available from Sir W. H. Bailey & Co Ltd—sole agents and distributors for the manufacturers, Dukes & Briggs Engineering Co. Known as the K-type, it is only 2⅛ in. long and contains a rotor in a perspex cylinder.

Tick **No 221** on reply card

Fast neutron monitor. Survey meter FN2B from the Nucleonic Corporation of America uses a dispersion of zinc sulphide grains in lucite as a scintillator. It is insensitive to slow neutrons and is unaffected by gammas from Co-60 up to 4r/h. Three ranges are available 0–5, 0–50, 0–500 neutrons/cm²/sec.

Tick **No 222** on reply card

Corrosion protection. Introduced by the B.B. Chemical Co. Ltd., the Bostik Endurion process is already widely used in America and was employed in parts of the nuclear submarine *Nautilus*. The process is a non-toxic chemical after-treatment applied to a base phosphate coating on ferrous metals.

Tick **No 223** on reply card

Steam valve. Known as the Bi-Seat, a new stop valve for controlling steam up to 300 lb/in.² and 500° F has been introduced by Sir W. H. Bailey & Co Ltd. Made in Monel and stainless steel, the valve is claimed to have a particularly fine control owing to a special type of seal.

Tick **No 224** on reply card

Pipe couplings. Ruston & Hornsby have concluded a license agreement with the Gray Tool Company of Houston, Texas, to exploit the latter's patents. Known as the Ruston-Grayloc, the connexions are claimed to offer many advantages in price, speed and efficiency.

Tick **No 225** on reply card

Plastic fans. Sturtevant Engineering in connexion with Acalor Ltd are now producing fans with an all-PVC casing and PVC-clad impeller. It is offered as an alternative to the all-fabricated PVC *Monogram* series with the advantage of safe, high operating speeds.

Tick **No 226** on reply card

No hands. Western region of British Railways are experimenting with a driverless trolley—the Robotug. Developed by EMI Electronics the battery-driven truck follows a single wire laid just beneath the flooring.

Tick **No 227** on reply card

Limit switch. Designated class 9007, type AW36, a new plug-in precision limit switch from Square D Ltd. has a micrometer adjustment for the roller, operable after the switch has been mounted and wired.

Tick **No 228** on reply card

Mains failure. Londex Ltd. have introduced an alarm bell which rings for two minutes after a mains failure. It is clockwork driven.

Tick **No 229** on reply card

Chopper. Advance information from Ericsson on new miniature model shows it is based on the company's well-known polarized relay.

Tick **No 230** on reply card

Counters. Counting Instruments' type 100 electric counters now available with push-button reset.

Tick **No 231** on reply card

Fans. New Q range from Standard and Pochin are suitable for conditions requiring low noise.

Tick **No 232** on reply card

INDUSTRIAL NEWSDESK

Olympia was successful

There was a record attendance of overseas visitors, from no less than 84 different countries, to the Engineering, Marine, Welding and Nuclear Energy Exhibition held at Olympia from April 16–30. This has encouraged the British Engineers' Association, sponsors of the exhibition, to plan additional approaches to certain key overseas markets. The first country selected is Canada and a special 60 show-car train will visit cities from Vancouver to Halifax during May and June 1960.

Among the general exhibits at Olympia there were several items which should prove of use in nuclear engineering projects. These included Rockweld's Vertomatic automatic vertical electro-slag welding machine. This equipment is manufactured by Rockweld Ltd. as the sole licensees for the UK of the Vus (Bratislava) patents and provides considerable economies in the welding of heavy fabrications in plate thicknesses of 2 in. and upwards. Another piece of equipment is the Andantex reduction unit which, while basically a sun and planet gear system, has many advantages over conventional units. By using moulded nylon to locate the planet pinions on their respective shafts, equilibrium on the various pinions is ensured. In addition by various mechanical, electro-mechanical or hydraulic actuators, it is possible to immediately change the speed ratio over a very wide range, i.e. from 480 : 1 to 1 : 1. These units are available for power drives between 3 and 80 h.p.

Where corrosive and misalignment conditions may occur together such as in coolers or fans, the Metastream range of couplings manufactured by Metaducts Ltd. are particularly suitable in that stainless steel flexible membranes are used in place of the conventional non-metallic bushes or rings and the general material of construction may be selected to meet specific requirements. On the H. M. Hobson stand a small range of Unibrix portable radiation shielding bricks were shown. A feature of these high density shot-loaded blocks is the very good external surfaces.

Getting inside Europe

The Babcock & Wilcox Company has appointed Ralph W. Deuster as European nuclear sales representative. In this newly created position, Mr. Deuster, with headquarters in Brussels, will maintain liaison with Euratom and represent B. & W. in European markets. After joining the company in 1955 as a nuclear systems specialist he was assigned for two years to sales liaison and has since been assistant to the manager of the propositions and contracts department.

Another US company increasing its activities in the European market is The Thompson - Ramo - Woolridge Products Co. and as a result of a licensing agreement with Intertechnique of France production of RW-300 Digital Control Computers will start immediately. Two such computers are being incorporated into the monitoring system for the 1148 uranium fuel cartridges in the first French commercial nuclear power plant, EDF-1, being built near Chinon.

To introduce a greater range of products through licensing arrangements into Europe, ACF Industries Inc. have set up a new British company, ACF

FOR LIAISON DUTIES WITH EURATOM
Ralph W. Deuster
(see 'Getting inside Europe')

(Great Britain) Ltd. This new organization will be responsible for issuing licences covering the products of the Carter Carburettor division; the American Car and Foundry division; and the electronic and electro-mechanical components made by ACF's Avion and Nuclear Products—Erco divisions.

Increased activities

An agreement announced on April 17 between Savage & Parsons Ltd. and Marconi's Wireless Telegraph Co. Ltd. will enable the remote handling division of Savage & Parsons to supply closed circuit industrial television equipment to nuclear research and experimental establishments. It will enable complete installations of mechanical or power-operated manipulators and Marconi Vidicon cameras with 14-inch picture monitors to be built and installed as single-coordinated units.

So as to participate fully in the European Common Market Plessey International Ltd. have formed a German company. This organization, Plessey Elemente Gesellschaft m.b.H. has a nominal capital of DM 200,000 and will be responsible for the manufacture of many Plessey products in the light engineering field, particularly those relating to hydraulic equipment. Production will be undertaken at Neuss, near Düsseldorf.

Lucky Mc get contract

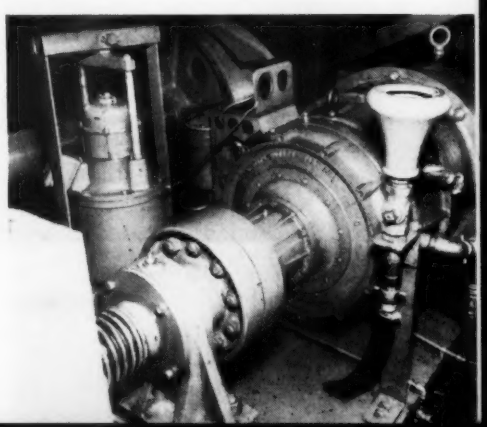
Another action by the United States AEC to extend domestic uranium production is covered by the contract signed May 1 with the Lucky Mc Uranium Corporation. This agreement becomes effective from July 1, 1959 until December 31, 1966, and covers an increase in ore processing from the present 833 tons per day to 980 tons daily. In addition a firm market will be established for a number of independent producers in the area by their 'dedicating' their ores to the Lucky Mc Mill on the basis of allocations.

Touring Britons

On May 4 a five-man delegation from the Water-tube Boilermakers' Association started a ten-day visit to Russia. This is a reciprocal visit following a tour made last year by a similar Soviet trade delegation to Britain. The British team will discuss the USSR's requirements and evaluate the possibilities of increasing British steam-raising plant in this market. Russian developments in water-tube boilers and technical problems formed part of the talks.

On April 18, Mr. J. E. C. Bailey, Chairman and Managing Director of Baird & Tatlock (London) Ltd. and Hopkin & William Ltd., left for a visit to Canada and the USA. During this visit Mr. Bailey addressed the Scientific Apparatus Makers of America at their Annual Conference, speaking on the European Common Market and how it

SPEEDING UP ERECTION. For the first time multi-motor torque converter derrick cranes are now being used in Great Britain; these were supplied by John M. Henderson & Co. Ltd., to Sir Robert McAlpine & Sons Ltd. The torque converter automatically gives infinite speed variation inversely as the hook load



will affect exports from non-member nations, including the British Commonwealth and the United States.

German expansion

During April two German industrial groups finalized agreements with British companies to be represented in the UK. William H. Capper & Co. Ltd. have been appointed agents for Demag and will handle mining equipment and compressors of all types. The British company will carry out the installation and undertake the design, fabrication and installation of associated pipework.

Birfield Tools Ltd. have been appointed sole licensees for the sale, installation and servicing of the complete range of equipment produced by the Hofmann Organization with the exception of a series of wheel balancing machines, already being manufactured under licence by another Birfield Group company. At a later date it is expected that Birfield Tools will also manufacture many of the machines covered by this new agreement. Of special interest in the nuclear engineering field are electrodynamic balancing machines with capacities up to 20 tons and suitable for rotors and turbines. Other such machines have been designed for the static balancing of fan blade assemblies and vibration testing of electric motor, blowers and pumps.

UK gets 'know-how'

As a result of agreements between Southern Instruments Ltd. and the Ampex Corporation of America, with its UK subsidiary Ampex Electronics Ltd., part of recently extended Southern Instruments factory at Camberley will undertake the full-scale manufacture of Ampex Tape Instrumentation Equipment.

Similar manufacturing and selling rights have been obtained by Elliott Brothers (London) Ltd. from Canadian Curtiss-Wright Ltd. for the CW nucleonic thickness measuring apparatus. If required, this type of instrument can be used to make and record a continuous measurement of moisture content.

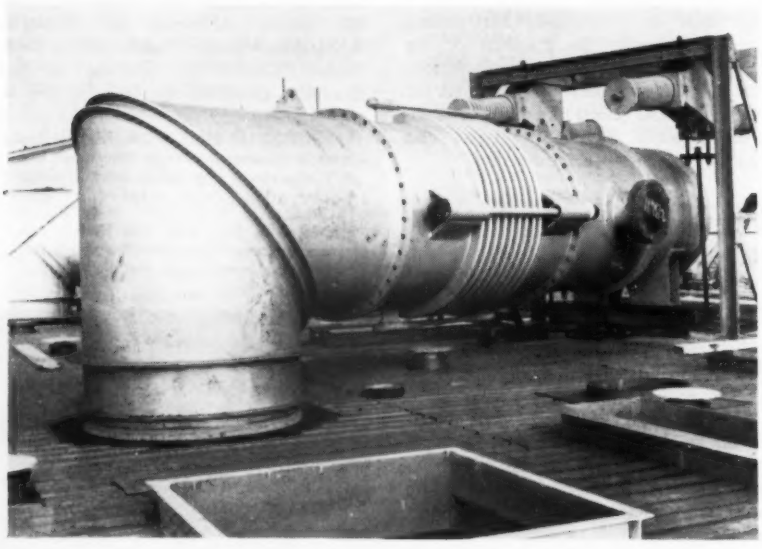
Developing ceramic control rods

Three of the ceramics shown in London during May at an exhibition by Morgan Refractories Ltd. are being developed for possible use as control rods. They are gadolinia/alumina, samaria/alumina and samaria/magnesia. Gadolinium has the highest known neutron absorption cross-section for any element, but samarium, with the second highest figure, seems to be more promising for this purpose. So far, Morgans have made 2 in. long × 2 in. dia. specimen sleeves for the AEA. Although more expensive than boron steel, ceramic rods would have the great advantage of lightness which could mean a reduction in drive mechanism size and costs. Their great disadvantage—brittleness—could be overcome simply and efficiently by enclosing them in metal cans.

NUMEC supplies Belgium

The Atomic Power Department of Westinghouse Electric Corporation, which is making the BR-3 reactor for Belgium, has placed a contract with Nuclear Materials & Equipment Corporation (NUMEC) for fuel. Over two tons of enriched uranium dioxide powder is required for fuelling this reactor and it will be formed into pellets by the Westinghouse materials manufacturing plant, which will, in turn, pass it onto the atomic power department for assembly into fuel elements.

PROGRESS IN ESSEX. One of the three CO_2 inlet ducts, with its combined bellows-spring hanger, mounted on the roof of No. 1 reactor, Bradwell nuclear power station



Permissible radiation summarized

The National Bureau of Standards, US Department of Commerce have accepted for publication, as NBS Handbook 69, a set of recommendations of the National Committee on Radiation Protection and Measurements under the title 'Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water.' These are revisions of the 1953 recommendations only and carry no legal implications requiring any changes in the law. The publication will be available from the Superintendent of Documents, US Government Printing Office in about two months time.

Italian products in England

The Plessey Company Limited have entered into agreement with Elettronica Metal Lux S.p.A. of Milan for the manufacture of Metallux Resistors in the UK. Under this new agreement, in addition to sole manufacturing rights in Britain for these metal film resistors, Plessey will hold sole selling rights for the UK and all the Commonwealth countries. A separate manufacturing unit is being formed within the Capacitors and Resistors Division of Plessey's and production is scheduled to start towards the end of the summer.

Freeing depleted uranium

An investigation to determine how and in what quantities industry may use depleted uranium for non-nuclear purposes has been authorized by the United States AEC. The three-month technical-economic study, to be completed in June, is being carried out by the Battelle Memorial Institute of Columbus, Ohio. This implements the Commission's decision to remove restrictions on non-nuclear uses of uranium and make it available to industry on an unclassified basis. The depleted material is now available in the form of uranium hexafluoride 'in substantial annual tonnage on a continuing basis' and may be processed to the metal, oxide or any desired compound.

N.S. 'Savannah' progresses

At the end of April, the 105 ton steel reactor vessel was completed and given its acceptance tests. In a special reinforced concrete and steel pit the vessel was subjected to prolonged hydrostatic pressure test at 3000 lb/in.^{2}—that is 1000 lb/in.^{2} above designed reactor operating pressure. Utilizing closed circuit televi-

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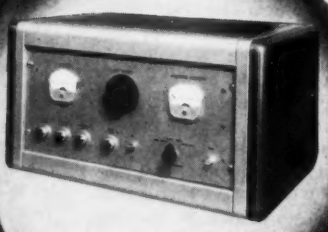

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USEFUL SITE AID. This vehicle is one of the 'Shorland' range of carriers made by Short Brothers & Harland Ltd., and which, from May 1, are marketed by Conveyancer Fork Trucks Ltd.

sion, the entire test was witnessed by United States AEC, Bureau of Ships Inspectors, US Coast Guard and manufacturers' inspectors. The equipment has now been shipped to Camden yards for installation into the *Savannah*.

NRTS extensions

During April AEC reviewed contract proposals for three extensions at the National Reactor Testing Station, Idaho. These were for alarm systems and special power services at the Flight Engine Test Facility and Shield Test (Pool) Facility in the Aircraft Nuclear Propulsion Area, by C-L Electric Co., costing some $30,000; the construction of a hot cell, shop and maintenance building at the Army Reactor Experiment Area, by Teller Construction Co., costing $666,500; and a contract to drill, case and test production well No. 2 at the Experimental Breeder Reactor No. 2 area by Wehling Well Works, valued $29,000.

Cladding analysis

The Bettis Atomic Power Division of Westinghouse Electric Corporation have awarded a contract to Controls for Radiation, Inc. (Con-Rad) for analyses of trace amounts of uranium in nuclear fuel elements cladding materials, such as zircaloy, zirconium and hafnium metals.

Draft code reviewed

The draft code of practice covering the custody, use and disposal of radioisotopes employed in industry, prepared by the Ministry of Labour last year, is now being examined by a number of industrial companies. These firms, including the manufacturers of the associated equipment, are studying it so that while it will be sufficiently stringent, it will be workable and can become part of the Factory Acts.

Development expansion

Two new blocks are being added to the Mullard Research Laboratories at Salfords to give an extra 45,000 square feet of floor space. These extensions will house the electronics, telecommunications, transistor applications and television laboratories as well as improving the facilities for the valve, semiconductor and materials research activities.

Another expansion, announced by Baird & Tatlock (London) Ltd., will double the research and development division to meet the increasing demand for Analmatic equipment and the redesigned standard laboratory instruments and apparatus. To cover these two aspects, the division has been split into two sections—Analmatic and General.

INDUSTRIAL NEWSDESK

Mainly discussions

London. The Annual General Meeting of the Institution of Mining and Metallurgy was held on May 21. Among the awards for the year, honorary membership of the Institute was conferred on Sir Alexander Fleck, K.B.E., D.Sc., F.R.S., in recognition of his outstanding services to the metallurgical industry.

Rome. From June 15 to July 5, the Fourth International Nuclear Congress and Exhibition on Electronics and Atomic Energy will be held by the Comitato Nazionale per le Ricerche Nucleari.

Venice. Sponsored by UN Educational, Scientific & Cultural Organization and the IAEA, a symposium on the immediate and low-level effects of ionizing radiations will be held between June 22 and 26.

Berlin. Deutscher Verband für Schweisstechnik e.V. will be holding their Great Welding Conference 1959 from June 23 to 26. The lectures cover the general subject of 'Welding Technology for Power Supply' and include reviews of nuclear power pressure vessels and the welding of specialized materials such as uranium and zirconium alloys.

London. Research & Control Instruments Ltd. in conjunction with the Department of Chemistry at the Imperial College of Science & Technology are holding a conference on X-ray diffraction and spectrography from July 6 to 10. Modern techniques and instrumentation for diffractometry and fluorescent analysis will be discussed and evaluated; extensive equipment will be made available for demonstration purposes.

Berkeley, California. The 1959 Cryogenic Engineering Conference will be held on September 2, 3 & 4, at the University of California. Technical papers and discussions will deal with engineering research and development at very low temperatures—below 150°K (−190°F).

York. The British Association for the Advancement of Science will hold its 121st Annual Meeting from September 2 to 9. Among the Physical Sciences and Engineering papers are 'High energy physical machines (CERN)' and 'Application of electronics in land transport.'

International Fairs

Belgium. The 11th Liège International Fair was held from April 25 to May 10. Two impressive features of this exhibition was the introduction of a range of Belgian nuclear engineering items, typical of the work at present being undertaken for Euratom projects and the absence of British manufacturers in this field. The only UK company present was Palatine Tool & Engineering Co. (Surbiton) Ltd., which showed a range of liquid metal valves, pumps and test equipment.

Japan. At the Tokyo International Trade Fair, held between May 5 and 22, the

NEW USE FOR SURFACE PLATES. Hawker Siddeley in the construction of their Jason reactor are using surface plates as bases for the graphite stacking of the inner and outer reflectors

Full steam ahead

A big step forward in the harnessing of nuclear power for peaceful purposes, the atomic power station at Chapelcross is now in commission. As main contractors on this project, The Mitchell Construction Company Ltd. were responsible for the construction of the four reactors and their cooling towers, the turbine hall, a sub-station for the South of Scotland Electricity Board and associated works.

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United States had the largest Government exhibit. The AEC made a special effort to acquaint the Japanese people with the latest US developments in nuclear energy, showing several exhibits from last year's Geneva Show and American industry included new items in the nuclear engineering field.

Portugal. Supporting the British Government exhibit at the Lisbon Fair, running from May 29 to June 14, Associated Electrical Industries Ltd. are showing a model of Metropolitan-Vickers Zeta, the thermonuclear reactor; and A.E.I.-John Thompson Nuclear Energy Co. Ltd., exhibit a model of a typical 150 MW single-reactor nuclear power station.

Spain. Nuclear materials and equipment will be included among the British exhibits at the Barcelona Samples Fair, to be held from June 1 to 20.

Scotland. During this summer, an atomic energy exhibition is being planned from Stromness, Orkney, to demonstrate the impact of nuclear power on the area. The project is being worked out jointly by the United Kingdom AEA and the Stromness Chamber of Commerce.

In brief

● **Chosen for Windscale.** The Ruston NFB gas bearing circulator has been selected by John Brown & Co. Ltd. for incorporation on the AGR's charge-discharge machine. This unit will provide gas circulation for cooling the irradiated fuel elements during the withdrawal process.

● **Bigger power stations.** The Central Electricity Generating Board are now working on the designing of the largest conventional power station yet projected in the British Isles. It is the Drakelow C, to be sited near Burton-upon-Trent, and is planned to have a total output of 1500 MW.

● **AEA provide first order.** At the official opening on April 24 of International Combustion's new heavy engineering shop, it was stated that the first contract received for work in this plant was from AEA for heat exchangers for Windscale's AGR. This new workshop is reviewed in this month's issue under 'Progress in Industry.'

● **British succeed in Sweden.** Atkiebolaget Atomenergi have placed a contract with Savage & Parsons Ltd. for 12 Master Slave Manipulators for the remote handling of radioactive materials, valued at approximately £15,000. This brings the total number of such manipulators exported up to 98.

● **Better results.** J. Carlton Ward, Jr., president of Vitro Corporation of America announced on Apr.l 28 during the company's annual meeting, that steady progress during the first part of 1959 had been made with a marked increase in new business and profits. Among the new contracts are two nuclear facilities for the AEC at Oak Ridge; one for a fuel reprocessing plant and the other a high-level radiation laboratory.

● **Valves for Latina.** Hopkinsons Ltd. have been awarded a contract for the supply of 66 in. main and 36 in. bypass 'Tansphere' type electrically-operated butterfly valves for the Latina nuclear power station. These will be sited within the concrete biological shield and will have to operate throughout their working life without maintenance.

● **Computer exported.** The first order from Australia for an E.M.I. Emiac II analogue two-module computer has been received by E.M.I. Electronics Ltd. from the Australian Government Factory, Melbourne.

● **Additional tests.** An addendum to BS 752/1958 'Test code for acceptance tests for steam turbines' has been published by the British Standards Institutions Numbered PD 3305, the new publication extends the function of the parent volume to include tests for back-pressure, pass-out and mixed-pressure steam turbines.

NAMES IN THE NEWS

Mr. R. S. Hewitt, deputy controller of Elliott-Automation has joined the board of the company. He has been associated with the Elliott Group since 1928.

Mr. S. A. Hiscock has joined the staff of the Lead Development Association.

Dr. W. F. Miller has been appointed director of the applied mathematics division of Argonne National Laboratory.

R. S. HEWITT

L. M. CURRIE

The Earl of Halsbury, until recently managing director of the National Research Development Corporation, has joined the board of Head Wrightson Processes Ltd.

Miss Dorothy Smith, an engineer in Metropolitan-Vickers motor engineering department, retired at the end of March after 43 years service.

Mr. A. A. Morris has been appointed by Northey Rotary Compressors to be their sales manager.

Mr. C. Robinson will hold the post of branch manager at Square D's newly opened Newcastle branch office.

Mr. C. L. Jaques, has been appointed chief generation engineer, Eastern division, of the Central Electricity Generating Board. Mr. E. C. Scott has become system operation engineer at the CEGB's headquarters. Mr. M. E. Peplow, formerly at the CEGB's Leatherhead research laboratories has been appointed regional research and development officer for the Southern, South Western and South Wales region of the board. Mr. P. K. Davis has been made divisional electrical engineer of the Board's Eastern division.

Dr. L. M. Currie has been elected a director of America's Babcock & Wilcox. Dr. Currie, is vice president in charge of the company's atomic energy division.

Mr. L. Rotherham, formerly with the UKAEA and now member for research of the Central Electricity Generating Board, has been co-opted to the council of the British Welding Research Association.

Mr. J. R. Wetch, Atomics International project engineer, has been appointed to the research advisory committee of the National Aeronautics and Space Administration.

Mr. G. H. Johnson has been made export manager of Bakelite Ltd on the retirement of Mr. E. J. Lassen.

L. ROTHERHAM

W. P. WARREN

Mr. E. T. Wilkinson has been appointed Rocol's southern area sales manager.

Mr. W. P. Warren, formerly commercial manager of the UKAEA's Industrial Group has joined the Powell Duffryn Group as sales manager of their subsidiary, Cambrian Wagon and Engineering Co.

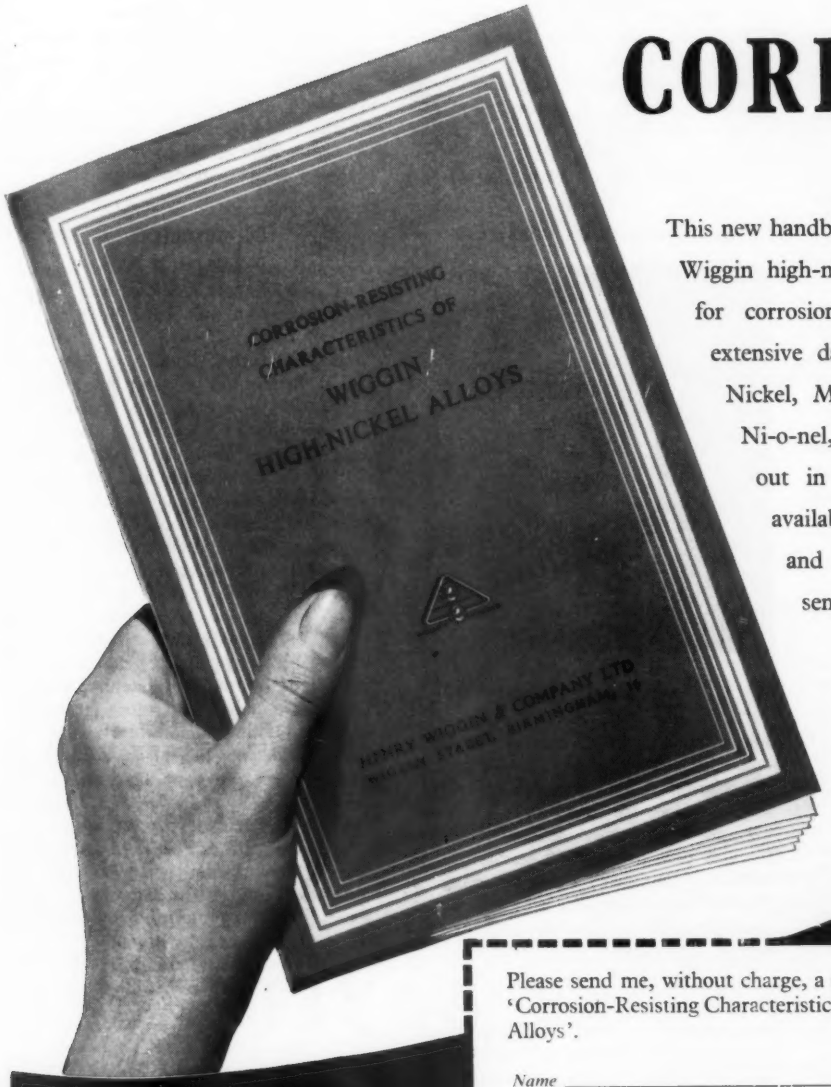
OBITUARY

Mr. K. R. Hopkirk, who until retirement last year was director and chief mechanical engineer of the British Thomson-Houston Company, died on April 24.

Mr. G. Bennett, manager of Automatic Telephone & Electric's Liverpool factories died on April 27.

Knowing where to find the answers on

CORROSION



This new handbook describes in detail the many Wiggin high-nickel alloys specially developed for corrosion-resisting duties. It includes extensive data on the properties of 'AT' Nickel, Monel, Inconel, Corronel B and Ni-o-nel, and gives results of tests carried out in many corrosive media. It is available, without charge, to designers and chemical engineers. May we send you a copy?

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They said...

points from papers, speeches, conferences

Trade prospects

During May, the future industrial prospects for nuclear engineering and electronics were reviewed at two annual conferences of professional organizations. At Folkestone, on May 9, Mr. J. H. K. Pendry, Chairman of the Association of Supervising Electrical Engineers, expressed a rather gloomy outlook. While he praised the present general export activities of electrical equipment and anticipated that such exports would continue to grow, he expressed doubts of nuclear power providing an economical means of electricity generation. Mr. Pendry went so far as to echo Sir Christopher Hinton's earlier opinions: if generating costs did not become competitive within the next few years, it would be necessary to swing back towards the use of conventional power plants. One of the reasons for these higher costs, said Pendry, was 'that the estimated value of the by-product plutonium has not materialized.'

On the other hand, when Mr. K. F. Dormer, President of the Institution of Plant Engineers, addressed the 1959 Harrogate Conference on May 7, a much more optimistic opinion was expressed. He said that he was proud of his members' activities on major projects, including the nuclear power stations, during the past year. The increasing capital outlay incurred by the introduction of special purpose machinery, electronic equipment and increased mechanical power available to each man, could be offset. Mr. Dormer said that the Plant Engineer should 'press for changes in methods, machinery and practices' and so enable this country to compete with foreign industry.

Fallout queries

'Radioactive fallout is a matter of great importance, said John A. McCone, Chairman of the United States AEC, addressing the Joint Committee on Atomic Energy on March 24, and his commission does not take the question lightly; nor have they dismissed it as unimportant to the people of either the US or indeed, the world. He went on to say that as long as he was head of the AEC he would 'not be a party to the suppression or distortion of any information bearing on the safety and health of the public.'

During the present financial year the AEC is spending $M18 in research on problems associated with radiation standards and protection. In addition, $M2¼ for sampling and analysis for both national and worldwide fallout studies and nearly $M½ for training in health physics and industrial hygiene will be expended. Funds for research and protection will, for the coming financial year, be increased to $M20 and nearly 2000 scientists and technicians will be involved.

'Active sampling programmes are being conducted in a number of other countries with whom we (AEC) exchange information. These countries are widely dispersed over the world and include for example, Japan, New Zealand, Norway, England and Brazil.' 100 stations in 37 different countries are conducting a gummed paper sampling programme and in addition 81 stations are regularly collecting soil samples.

JOHN A. McCONE
... evidence not suppressed

While the AEC is the only US government agency that has carried out extensive research on worldwide fallout, the Department of Defense (DOD) did conduct a series of experiments recently. These results are not in agreement with AEC's but General Loper, spokesman for the DOD, hopes the differences will be resolved. The AEC's chairman went on to say that he had been told 'that there has been no attempt at any time to suppress or modify the DOD report in the interest of reconciling these differences of scientific judgment.'

Urging early government and international reviews into the subject, John A. McCone concluded by saying 'I am fully prepared to assist any competent body in developing the facts now in controversy on the fallout issue and to disclose these facts to the public. I am confident that the AEC has not been derelict in its studying of radioactive fallout and in revealing the conclusions of such studies when the data has been collated and evaluated. If, however, your Committee finds any shortcomings on the Commission's part, I pledge you to initiate immediately the most vigorous and comprehensive corrective measures possible.'

It appears that political and inter-departmental differences form as big a problem as radiation hazards themselves in the US Government. In recent weeks a similar state of affairs has appeared to exist in the British Parliament.

Nuclear fuel resources

A comprehensive survey of the uranium and thorium resources of the British Commonwealth was made by S. H. U. Bowie, B.Sc., M.I.M.M., of the Atomic Energy Division, Geological Survey of Great Britain, in a paper read before the Royal Society of Arts on April 23. His conclusions were that there was a vast potential of nuclear raw materials in the Commonwealth and that 'many more areas rich in uranium undoubtedly exist, but whether there are many more as large and as rich as Blind River (Canada), or from which uranium can be produced as a by-product of some other metal, as in the Witwatersrand Basin (South Africa), is not so certain. In addition to these two major fields, the Copperbelt of Northern Rhodesia probably offers most hope as a future large-scale supplier of uranium, while the Blind River field and the place deposits of India will produce the bulk of the world's thorium. At Blind River and Bancroft there are considerable deposits of thorium and reserves are estimated to total some 200,000 tons. Assuming a production of uranium oxide of 10,000 tons a year, some 5000 tons of thorium oxide might be recoverable as a by-product.

Current estimates of production in 1958 and reserves of uranium and reserves of thorium (in tons) are:—

	U_3O_8 PRODUCTION	U_3O_8 RESERVES	ThO_2 RESERVES
Canada	13,537	413,000	210,000
South Africa	6,245	330,000	15,000
USA	12,560	221,000	50,000
France	815	50,000	—
Australia	700	15,000	50,000
Belgian Congo	1,000	10,000	—
India	—	—	300,000
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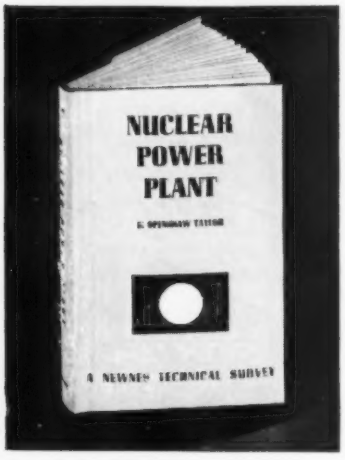

This book opens with a concise account of world energy requirements and resources, present and future. It goes on to deal with nuclear and reactor physics, types of reactors, reactor engineering, instrumentation and control, and the economics of nuclear power stations. The appendices contain comprehensive tables of elements and a chronology to reactors. 30s. net.

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Book Reviews

Three years' progress

Progress in nuclear energy—Medical sciences, Volume 2 Edited by J. C. Bugher, J. Coursaget and J. F. Loutit London 1959: Pergamon Press 288 pp £5 5s

The second Geneva Conference reported the progress that had been made in the intervening three years since the first conference. In the medical field it has been less spectacular than in some other spheres, but in spite of this, six sessions were devoted to medical and biological sciences. Not all the papers presented at the conference have been included in the current volume, but nevertheless it makes an imposing collection of papers and one which gives a fair representation of the content of the conference.

The nature of the dose-response curves for many different effects has received much attention, throwing in turn doubt about the validity of many over-simplified generalizations. Significant data, both from the laboratory and from epidemiological observation, is put forward which is helpful in the application of small probabilities to large population, a situation which is especially important in the present nuclear age.

There are many practical papers included on health and safety in nuclear operations as well as papers dealing with specific hazards, e.g. 'Inhalation hazards in the nuclear industry,' 'Detection of Pu-239 in wounds.' There is an important paper on 'The uses of radioactive isotopes in medicine' (UN Survey) as well as eight papers on 'progress in teletherapy.' Altogether the volume includes 25 of the papers presented.

Denis Taylor

Tools for engineers

Transform Method in Linear System Analysis by John A. Aseltine London 1958: McGraw-Hill 316 pp Price £3 6s

For an engineer, mathematical transforms are tools which help him to study physical problems. He wants to know what these tool are, and how and when to use them. Furthermore, he wishes to attain this object without having to fight his way through a barricade of advanced mathematical entanglements. Being a lecturer in engineering, Dr Aseltine has fully appreciated this fact when writing his book. He has supported most of his mathematical arguments with physical reasoning and examples. Where the mathematics has become too involved, he has stated the results without proof but has given adequate references to where the proofs may be found.

The first eleven chapters of the book are concerned with Laplace transforms and their applications to electrical networks and mechanical systems. Two of these chapters deal with techniques of control system analysis including frequency response and root locus methods. On the latter subject, the author writes with some authority, having had considerable industrial experience in the field of control systems. One chapter is devoted to the Laplace transform solution of partial differential equations. The final six chapters are given over, one each to Fourier series, Fourier transforms, Z transforms (for solving difference equations), Mellin transforms, and two to systems with random inputs.

Sufficient references are given for anyone who wishes to pursue any of the topics further. It is a pity, however, that nothing more than reference is given on methods of polynomial factorization, because this problem often occurs when using Laplace transforms. Nevertheless the book should have a wide appeal amongst engineers, and particularly control system engineers, of graduate level.

A. P. Roberts

This review originally appeared in CONTROL

A health physics must

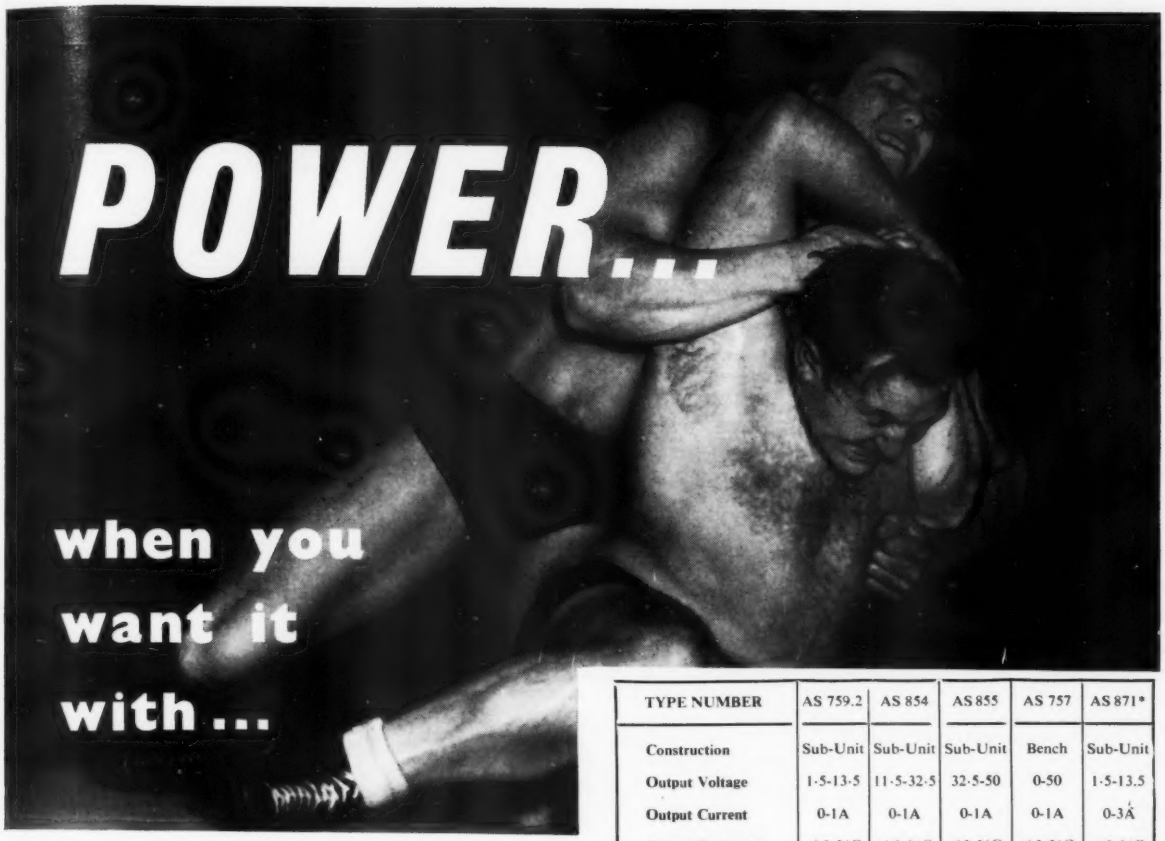
Recommendations of the International Commission on Radiological Protection (September 1958) London 1959: Pergamon Press Price 3s 6d

This is the latest version of the Recommendations which have been in general use since 1955. Since then there have been considerable changes in the light of new knowledge and experience. In particular there is a complete revision of the maximum permissible dose for occupational exposure which is now fixed at 3 rems during any consecutive period of 13 weeks. Obviously no one involved in health physics or health physics instrumentation can do without this book which, with its very reasonable price, is within reach of all.

For pump owners

The Pump Users' Handbook Herbert Addison London 1959: Pitman 122 pp Price 37s 6d.

The British Pump Manufacturers' Association commissioned Professor Addison to write for them a comprehensive yet concise handbook for pump owners and users. The author is of course a well-



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Output Resistance	< 0·01Ω	< 0·01Ω	< 0·01Ω	< 0·01Ω	< 0·01Ω
Output Impedance *(to 100 Kc/s)*	< 0·35Ω	< 0·35Ω	< 0·35Ω	< 0·35Ω	< 0·35Ω
Stability Factor	> 200: 1	> 200: 1	> 200: 1	> 200: 1	> 200: 1
Ripple and Noise *(Peak-to-Peak)*	< 1 mV	< 1 mV	< 1 mV	< 1 mV	< 1 mV
Dimensions (W x H x D)	7¾" x 5⅛" x 6 5/16" (197 x 139 x 160mm)	6⅝" x 5⅞" x 7 3/16" (168 x 149 x 182mm)	7¼" x 6½" x 7 13/16" (184 x 159 x 200mm)	12¾" x 8" x 13" (325 x 203 x 330mm)	8 5/16" x 6½" x 9 3/16" (210 x 172 x 233mm)
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TYPE NUMBER	AS 872*	AS 870	AS 873*	AS 758	AS 852
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Output Current	0-3A	0-3A	0-3A	0-10A	0-10A
Output Resistance	< 0·01Ω	< 0·01Ω	< 0·01Ω	< 0·01Ω	< 0·01Ω
Output Impedance *(to 100 Kc/s)*	< 0·35Ω	< 0·35Ω	< 0·35Ω	< 0·2Ω	< 0·2Ω
Stability Factor	> 200: 1	> 200: 1	> 200: 1	> 150: 1	> 150: 1
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known writer on the subject and the present book conforms closely to his approach to the subject. It would, one feels, however, not be very comprehensible without some knowledge of Addison's *Treatise on Applied Hydraulics* or his *Centrifugal and other Rotodynamic Pumps*. Given this, however, the book should prove a useful work, especially as it covers subjects such as installation and trouble tracing which are not dealt with in his more theoretical works.

The *Pump Users' Handbook* also contains a useful table of the type of pump manufactured by the members of the BPMA.

In brief

Chemistry of Nuclear Power J. K. Dawson and G. Long London 1958 : Newnes 208 pp. Price 30s.

This is a very readable little book by the leader and a member of the reactor chemistry group at Harwell. It is introductory in nature and does not demand an extensive knowledge of chemistry.

Radiation Biology and Cancer Texas 1959: University of Texas Press 493 pp Price $8.50

This is a collection of papers presented at the Twelfth Annual Symposium on Fundamental Cancer Research, 1958, together with verbatum reports of the discussions.

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CATALOGUES AND BULLETINS

Steel foundry service. New 28-page booklet from The North British Steel Foundry has an 11 page at-a-glance reference section in which the mechanical properties, chemical test requirements and equivalent specifications are given for 31 steels. Services and facilities offered by the firm to customers are described.

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Bearings. Two impressive spiral bound folders from Ransome & Marles Bearing Co contain technical information on the use of ball and roller bearings and there is a comprehensive catalogue of the firm's range.

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Valve and filter units. Three leaflets from Sperry Gyroscope describe with diagrams a micron filter unit, a servo valve drive amplifier and an electro-hydraulic servo valve.

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Air flow. A series of friction charts for straight ducts and pipes, originally produced by R. H. Young and J. M. Gasiorek for Sturtevant Engineering, have now been made available to engineers interested in this field. Price 7s 6d.

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Correction curves. Six page booklet containing correction factor curves for their flow meters has been issued by Fischer and Porter.

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Pipe insulation. Recently patented system of placing insulated pipework underground is subject of data sheet from Stillite Products. Material recommended is Stilag and technical data number 7 describes this.

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Tape spooler. Intended primarily for use with their high speed tape readers, types TR2, TR2B and TR5 Ferranti have produced a spooler suitable for handling the three standard widths of tape. Leaflet describes.

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Metal cutting machines. Range of cutting machines are described and specified in booklets from the Midland Saw & Tool Co. In the general purpose range tools have been specially developed for machining graphite.

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Isotope containers. A standard range of isotope coffins and carriers is now offered by Westover Nuclear Equipment who have issued a descriptive leaflet and price list.

Tick **No 256** on reply card

Scintillators. Bulletin number 591 from Pilot Chemicals Inc. gives cost and technical information on scintillation grade fluorescent chemicals and plastic scintillators.

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Welding rods. Recent literature from Suffolk Iron Foundry illustrates a new method of joining cast iron by bronze-welding.

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Radiation protection. Article entitled 'The practical aspects of radiation protection' by F. L. Veale has been issued in leaflet form by Research & Control Instruments.

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Valves and driers. W. C. Holmes & Co in their well illustrated publications numbers 76 and 77 describe the Holmes-Western gas valves and Holmes-Kemp driers.

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Automation. New Solartron literature available includes brochures on analogue computers, electronic instruments, response analysers. There is also a technical article on analogue computer techniques.

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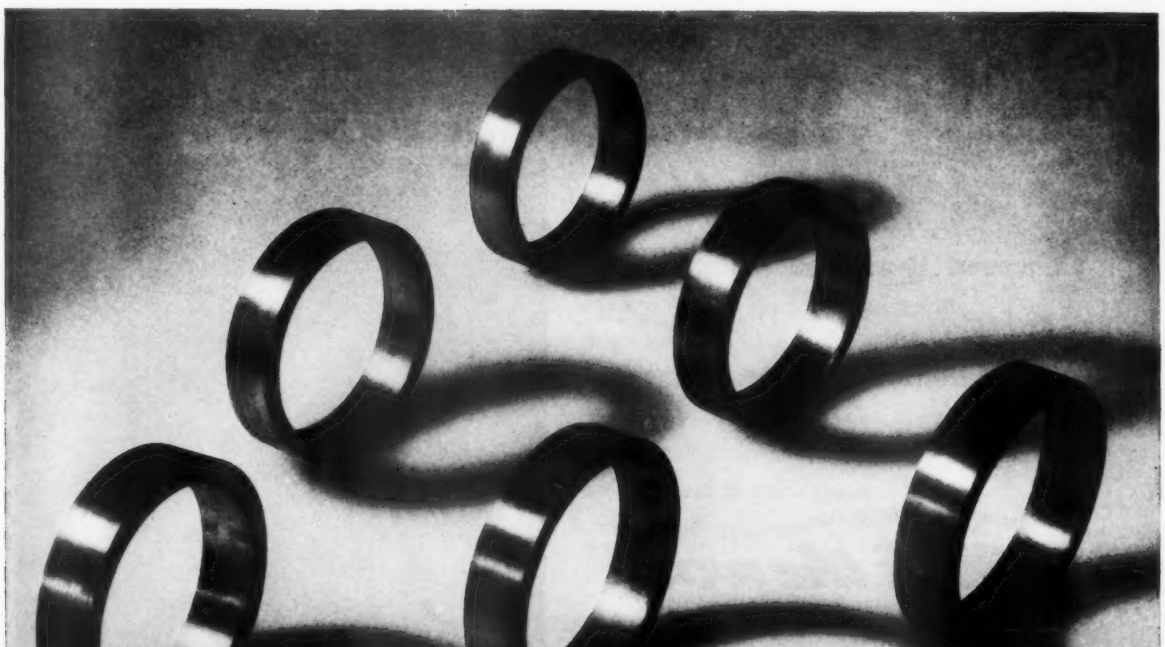

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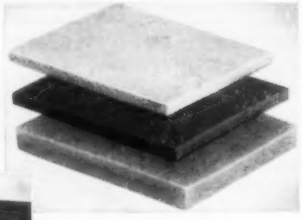

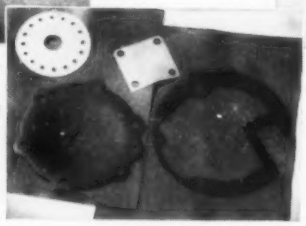

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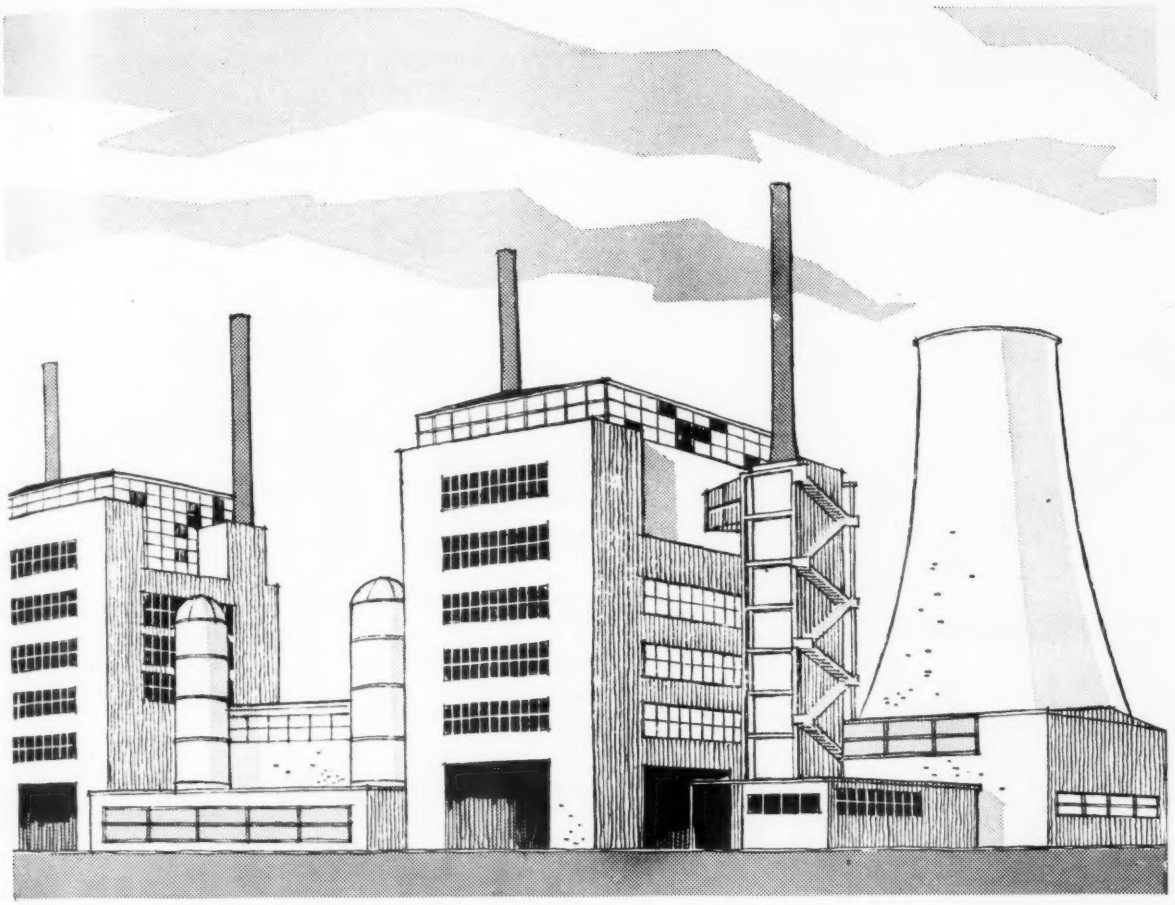

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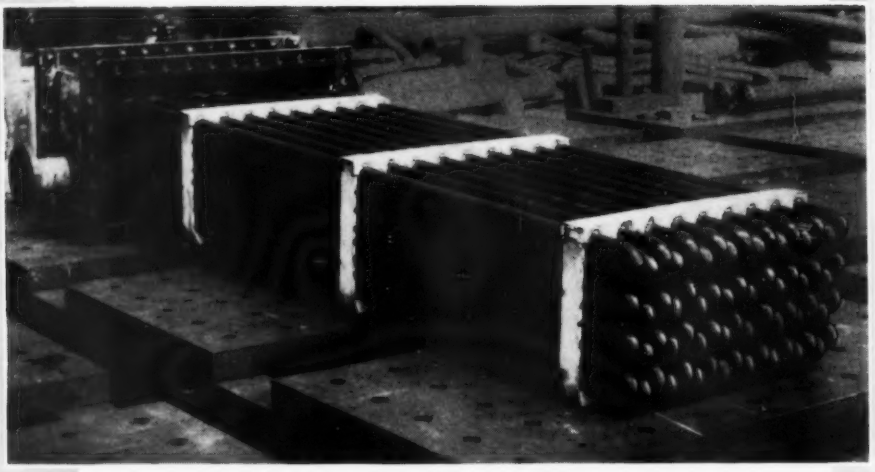

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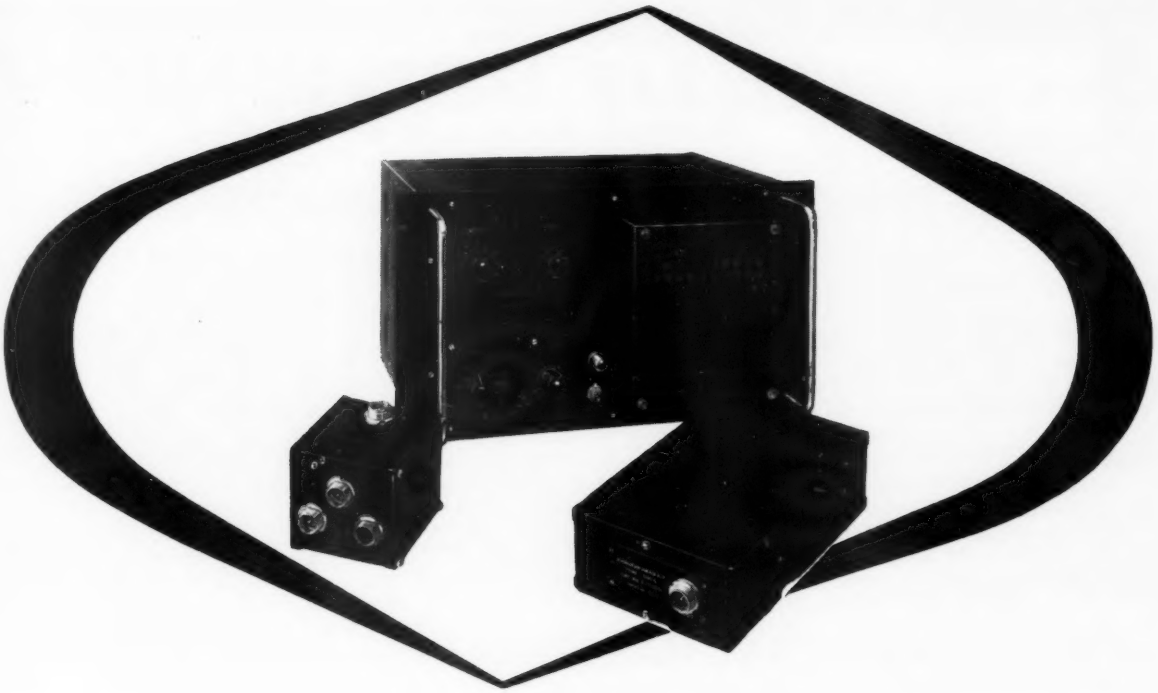

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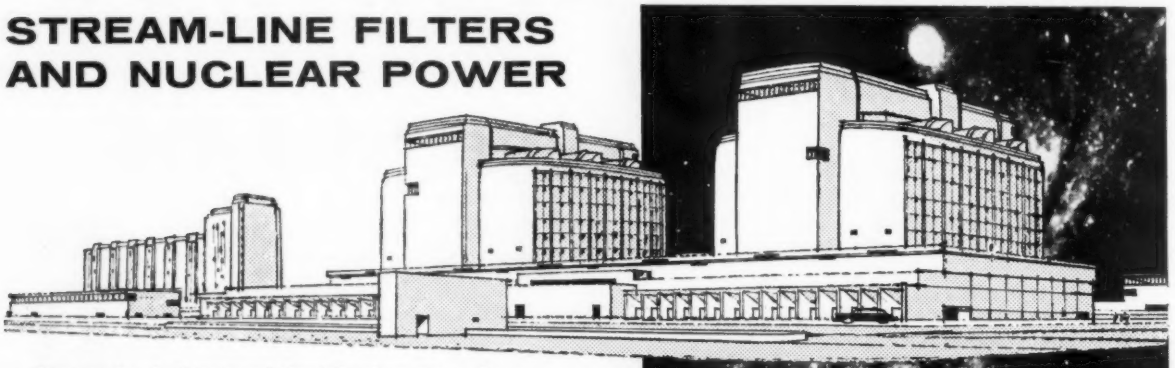

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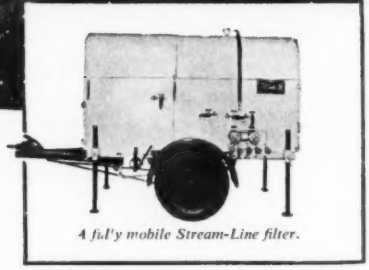

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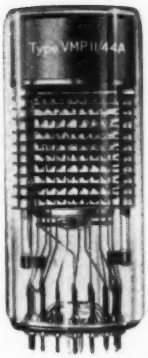

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For alpha scintillation counting, the VMP 11/44/C is available.

All of the above tubes are available with windows of quartz for ultra-violet spectroscopy and larger diameter photomultipliers employing the same venetian blind structure can be supplied.

The specification below gives details of these photomultipliers with suggested applications. Further details are available on request.

SPECIFICATION

Type	Cathode Type	CHARACTERISTICS (AVERAGE)					Price	Applications
		Cathode Sensitivity μA/Lumen	Overall Sensitivity A/Lumen	Overall Voltage	Dark Current at S.	Max. Current Linear Dynode Chain mA		
VMP 11/44/A	S11	55	2000	1400	0.08μA	50	£40	High resolution spectrometry. Low activity counting of low energy radiation
VMP 11/44/B (CV.2316)	S11	50	200	1200	0.03	50	£30	Scintillation counting
VMP 11/44/S	S9	30	200	1200	0.003	50	£30	Low energy counting
VMP 11/44/C (CV.2317)	S11	20	20	1500	0.05	50	£15	Alpha particle monitors

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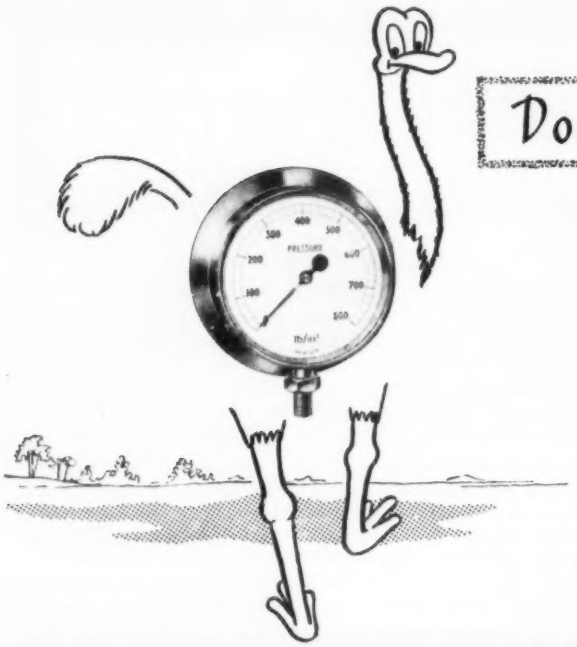

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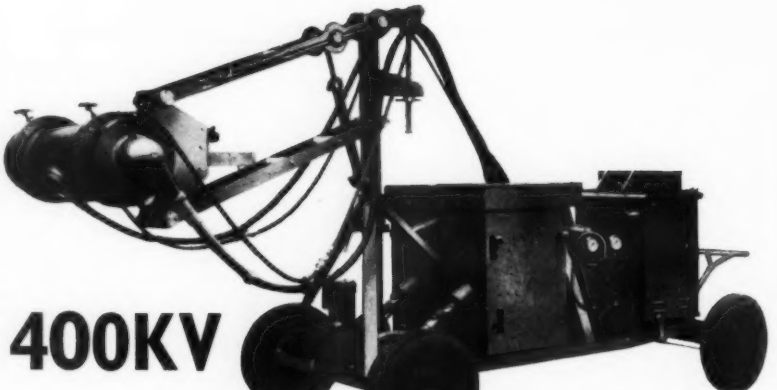

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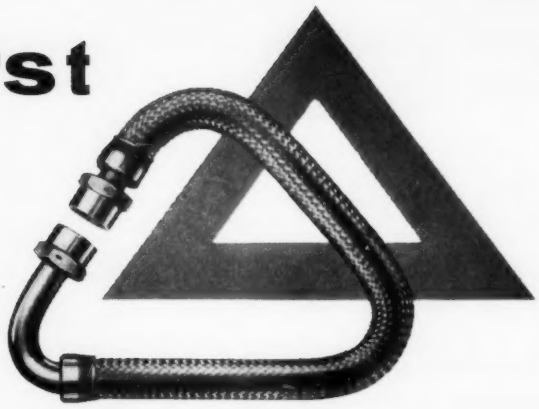

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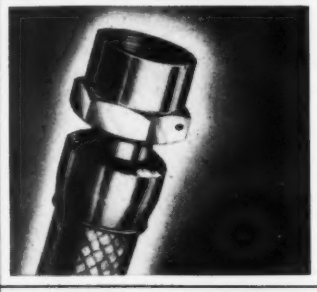

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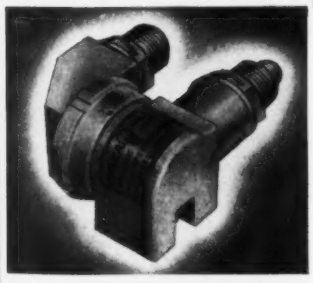

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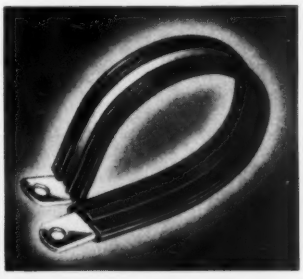

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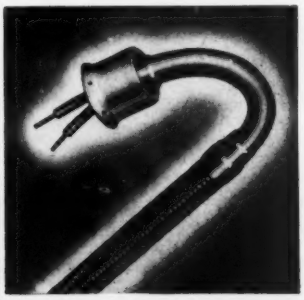

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supplied in densities
16.8,17.0,17.5,18.0g/cc(nominal)

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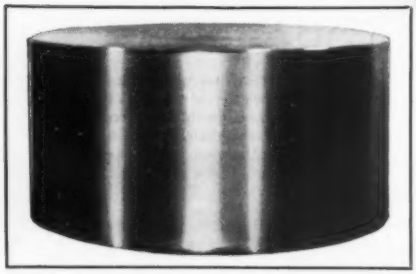
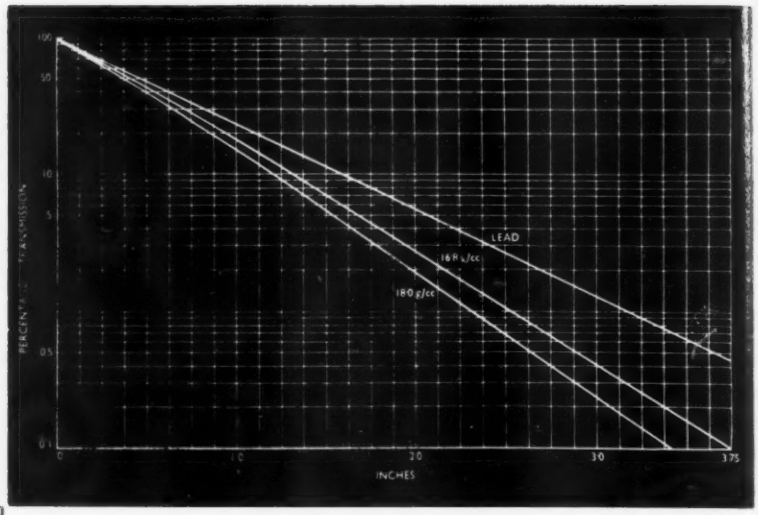


The above piece of G.E.C. Heavy Alloy was made for the United Kingdom Atomic Energy Authority. It weighs 660 lb.



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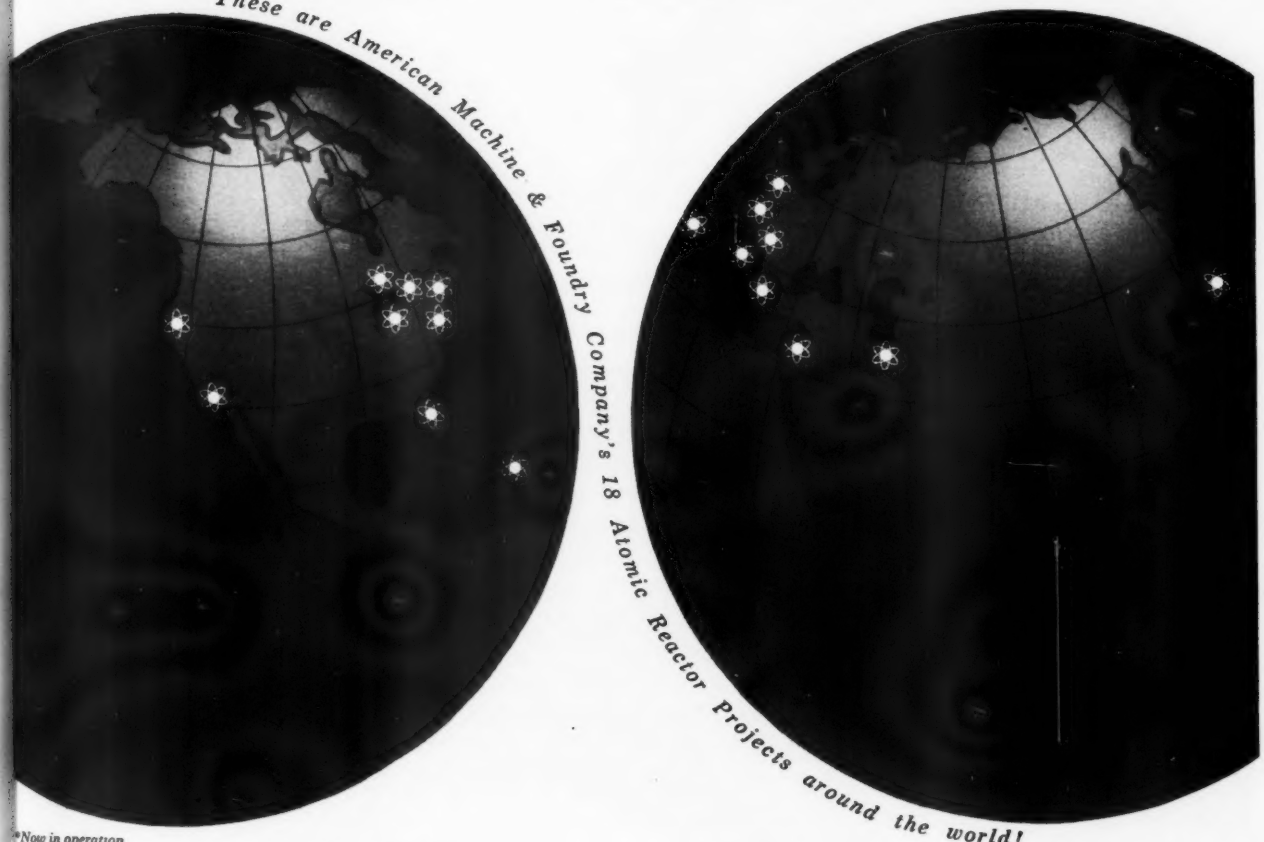

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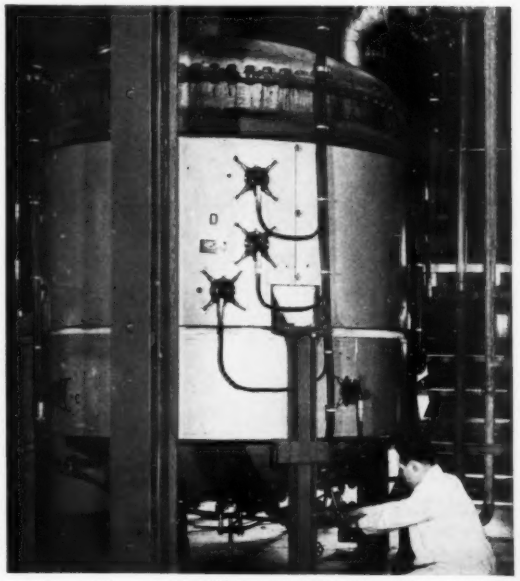

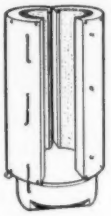

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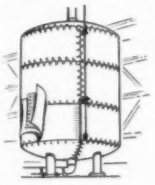

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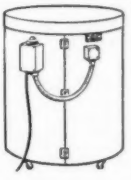

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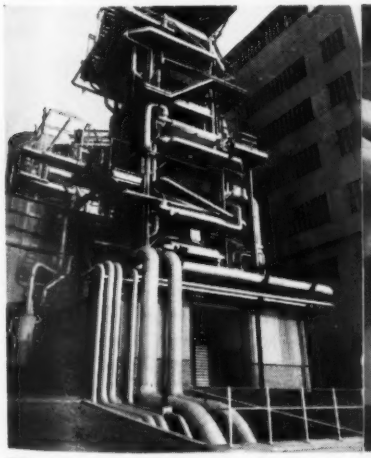
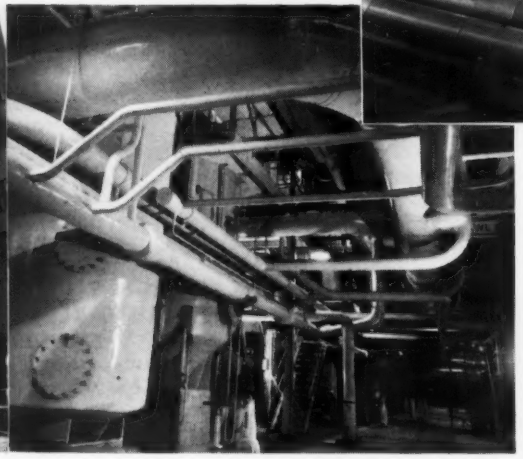
High Pressure and Low Pressure Steam Pipes leading from No. 1 Reactor to the turbine hall

One of the Heat Exchangers on No. 1 Reactor showing steam pipes in the foreground



Pipework under turbine operating floor



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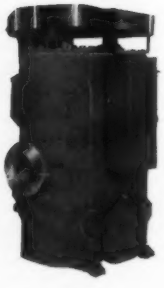

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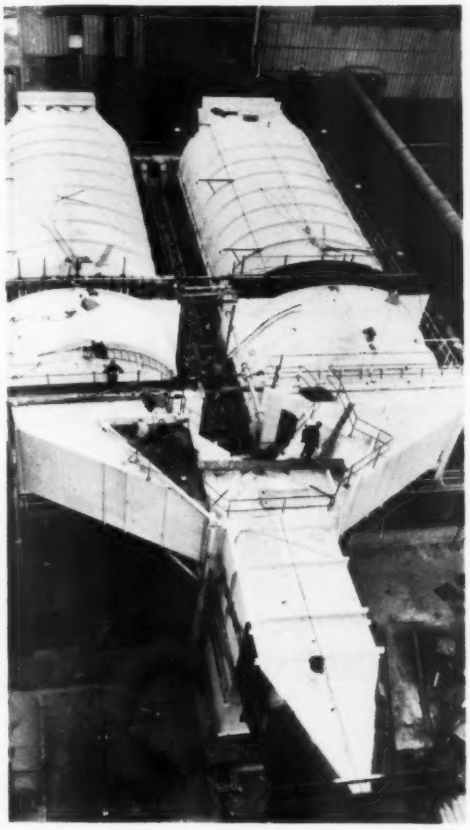

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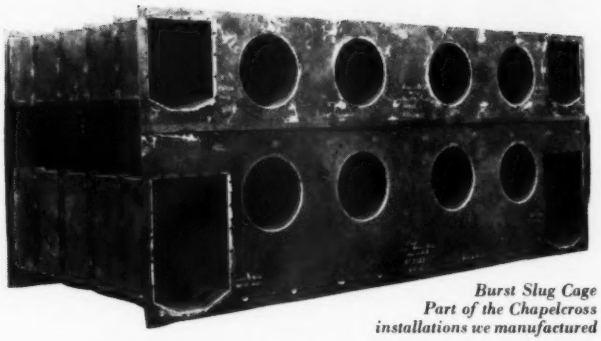

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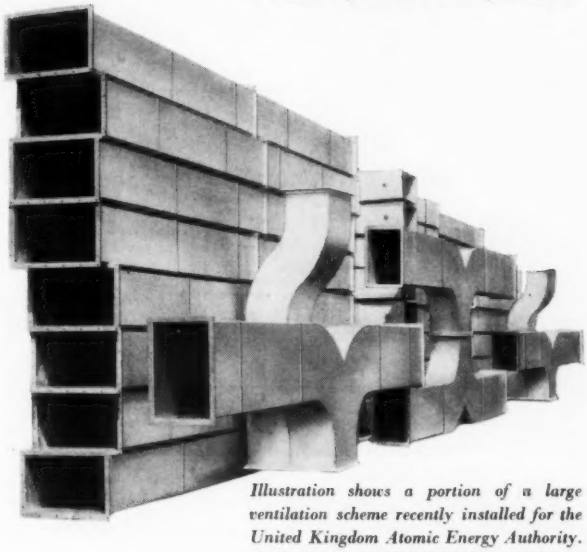

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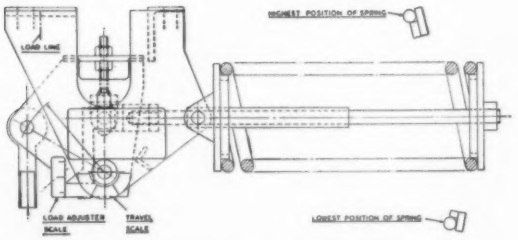

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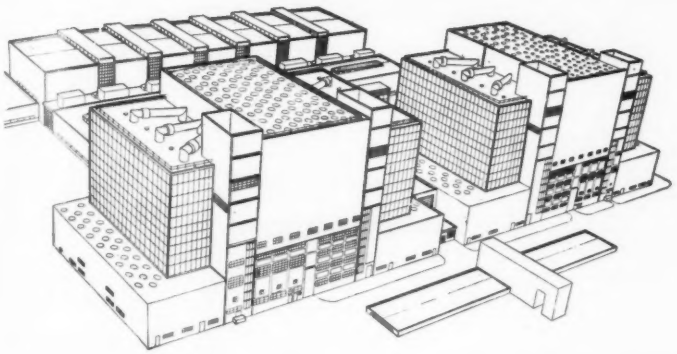

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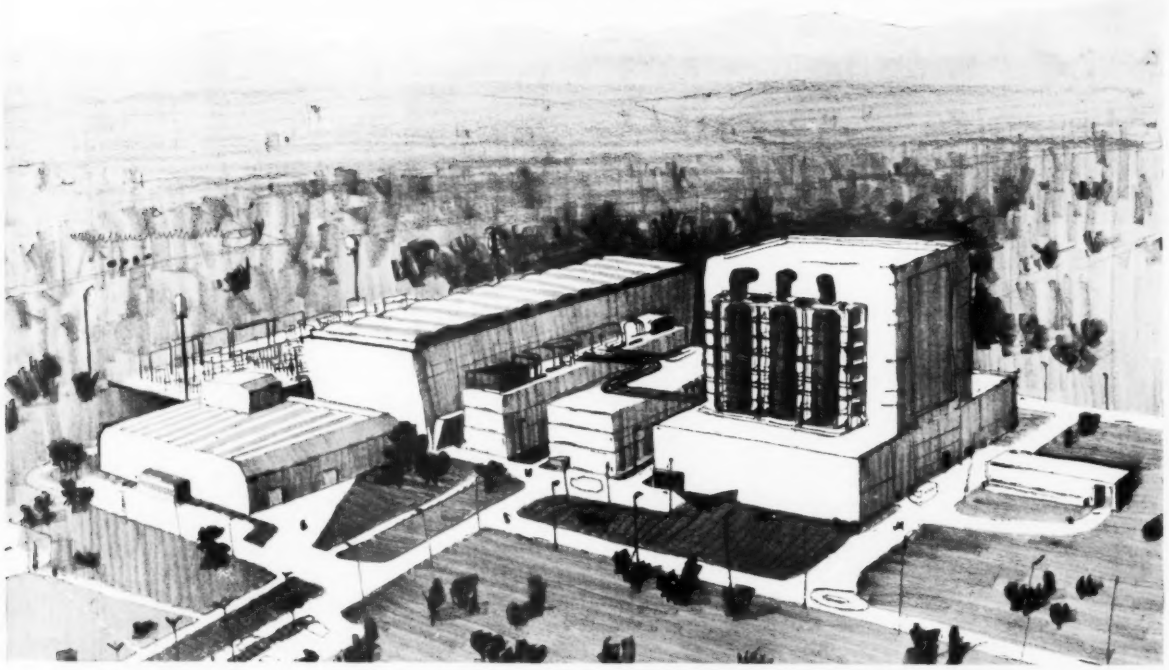

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London Office: 59 VICTORIA ROAD, SURBITON, SURREY. Tel.: Elmbridge 9793

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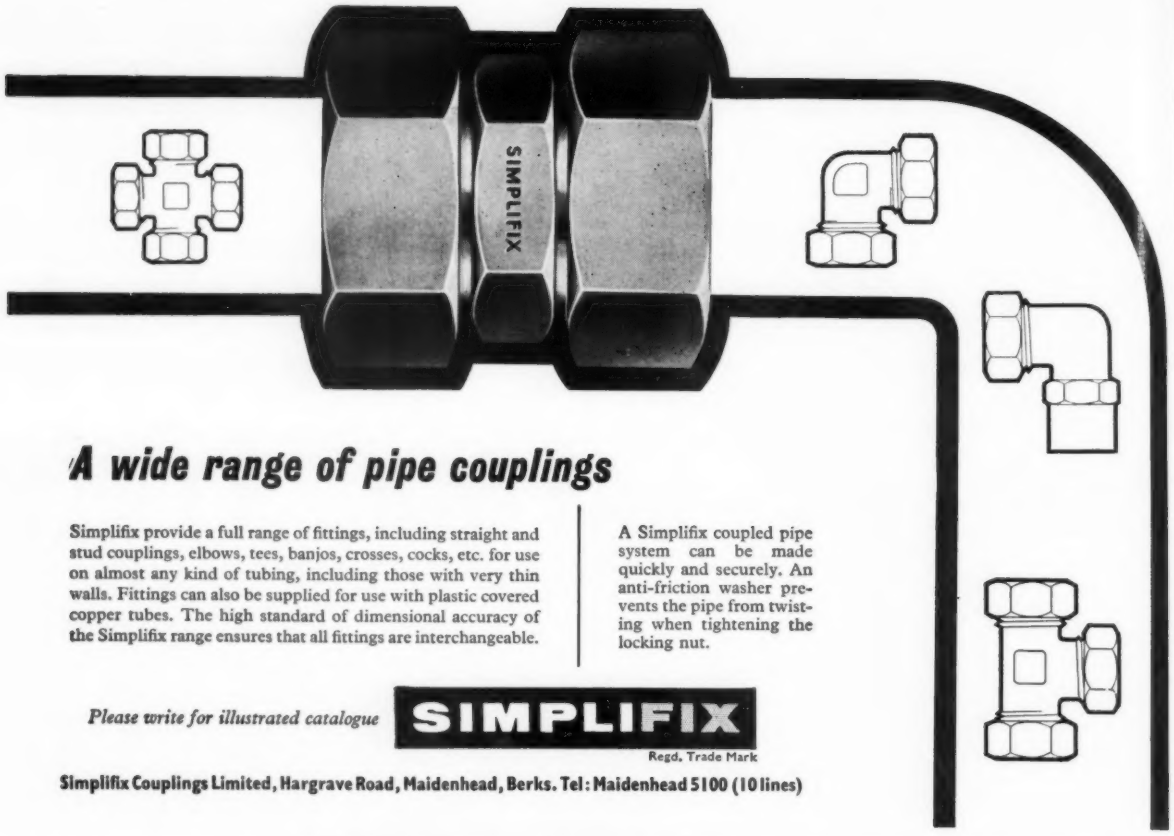

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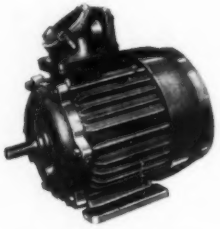

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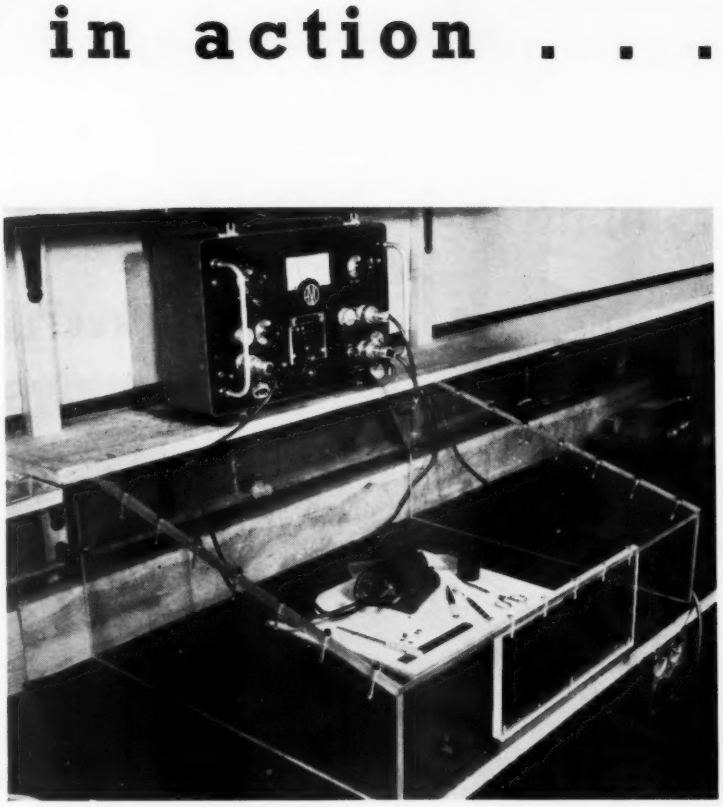
AVO in action . . .

The photograph shows an AVO "D.C." Amplifier Type 1388 being used to measure current of the order of 10^{-13} A in the ionisation chamber of an "Avo" Radiac Survey Meter. A radio-active source is being used to calibrate the instrument and a Perspex screen is employed to protect personnel from Beta radiation.

This is a typical example of how the AVO organisation, working in conjunction with Government research authorities, continues to make its contribution in the fields of modern scientific development and industrial progress.



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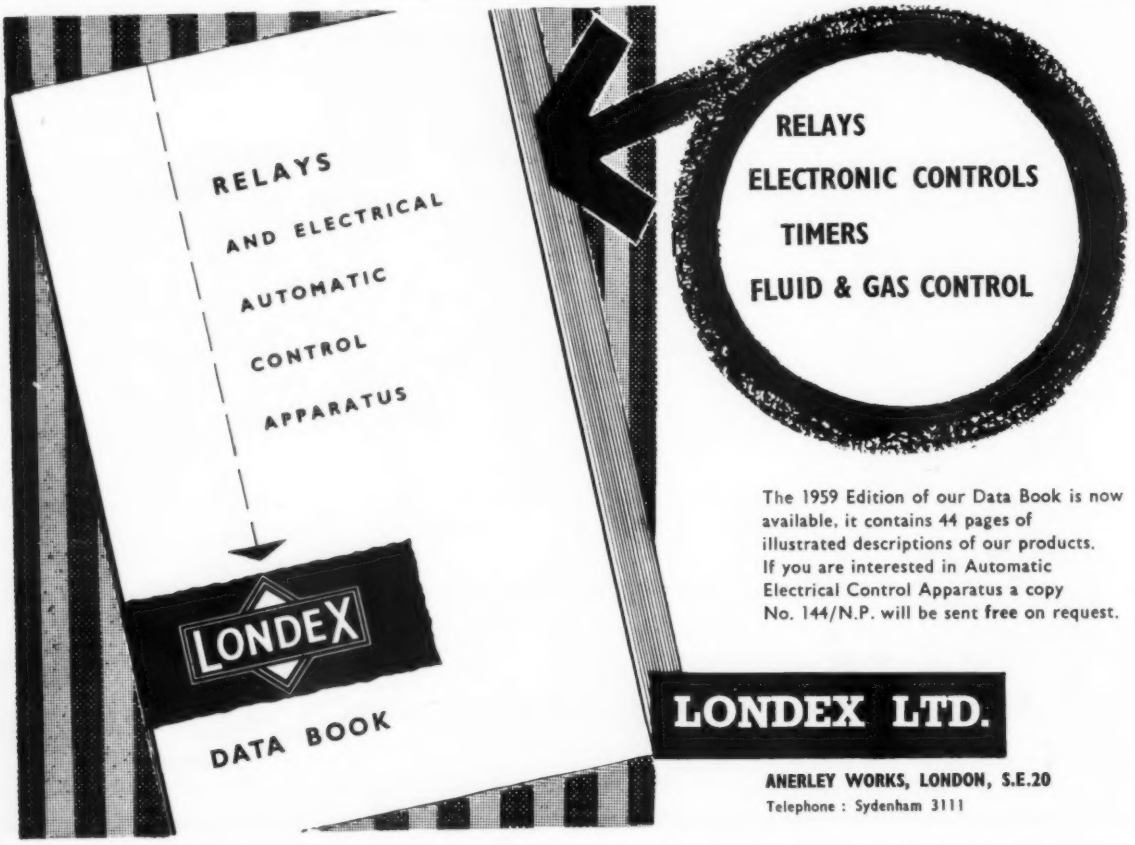

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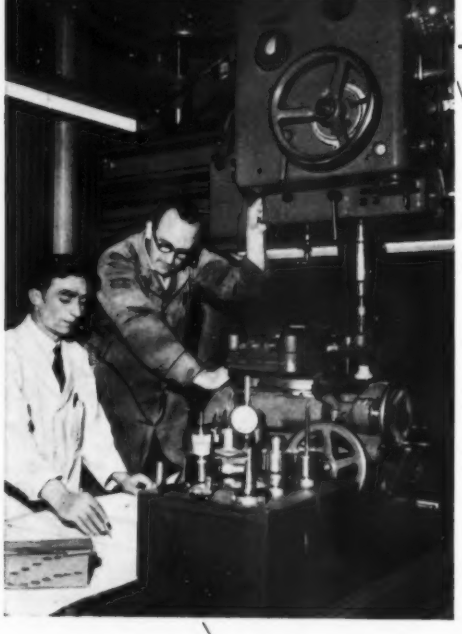

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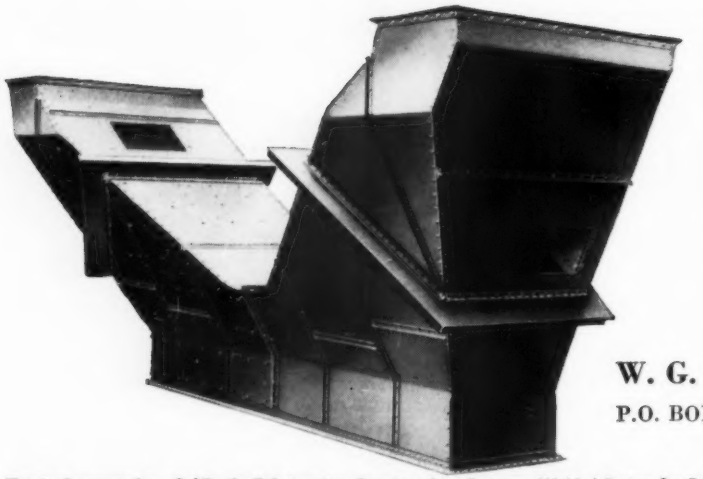

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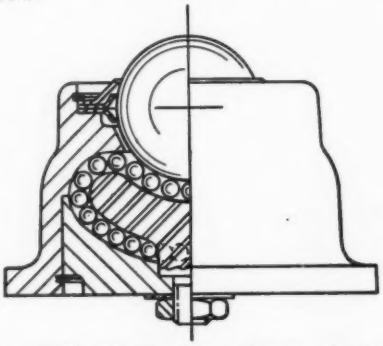

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讀者サービス

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TOTAL	*160*	*FOR 3 POWER STATIONS*

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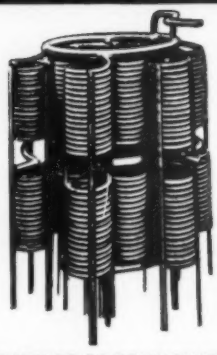

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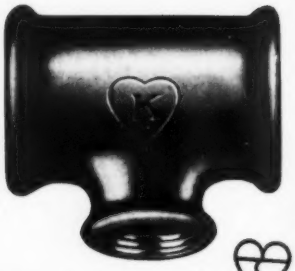

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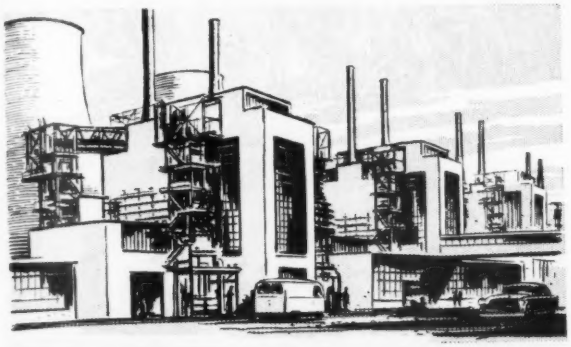

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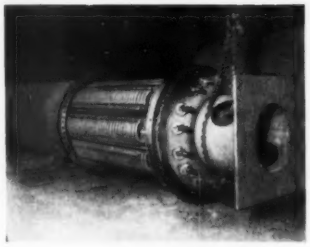

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PRESSURE & FLOW SWITCHES

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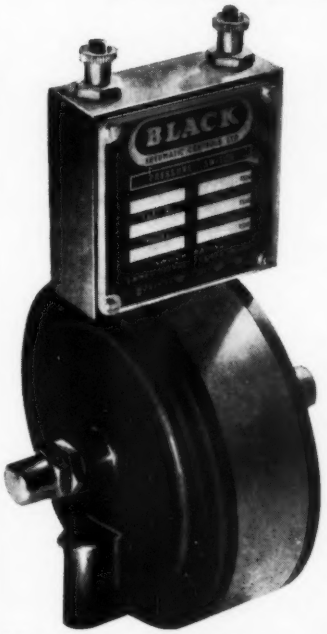

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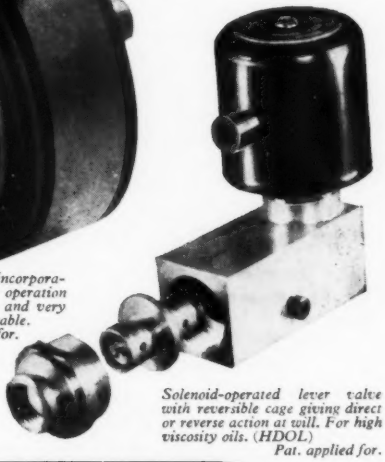

Solenoid-operated lever valve with reversible cage giving direct or reverse action at will. For high viscosity oils. (HDOL) Pat. applied for.

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AUTOMATIC CONTROLS LTD
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LEAFIELD - CORSHAM - WILTSHIRE
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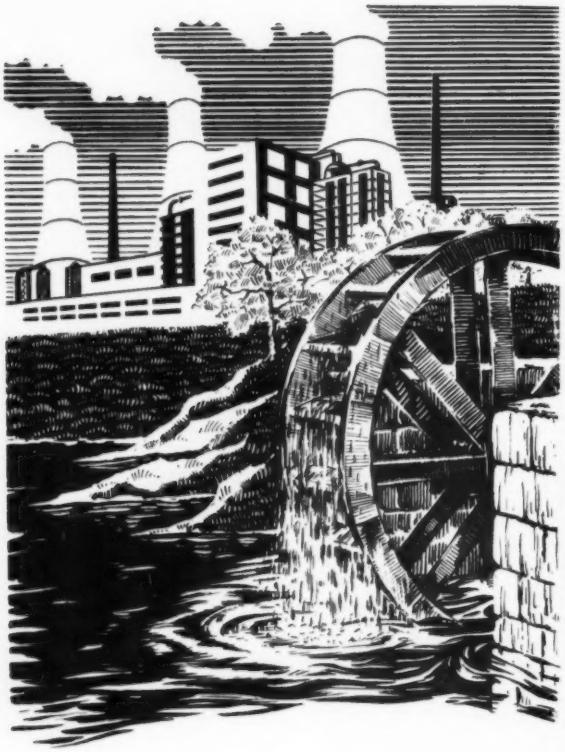

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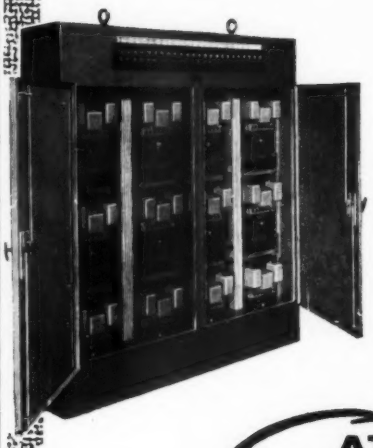

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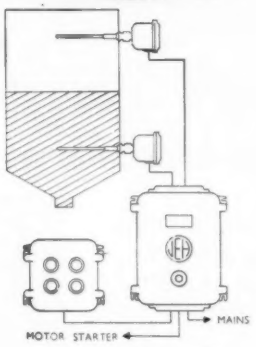

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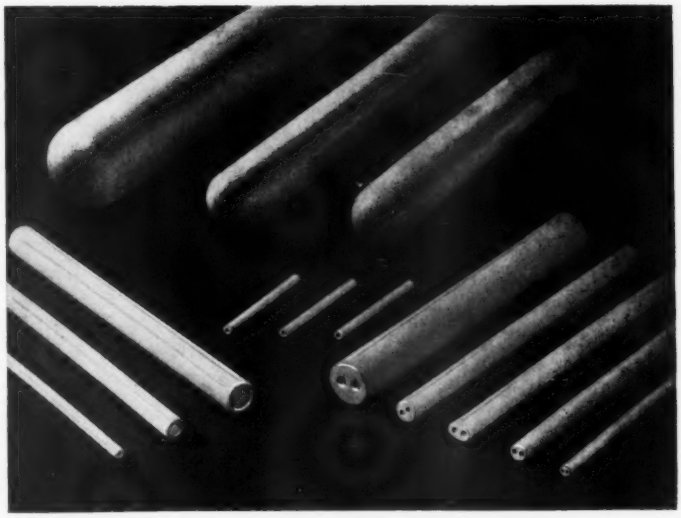

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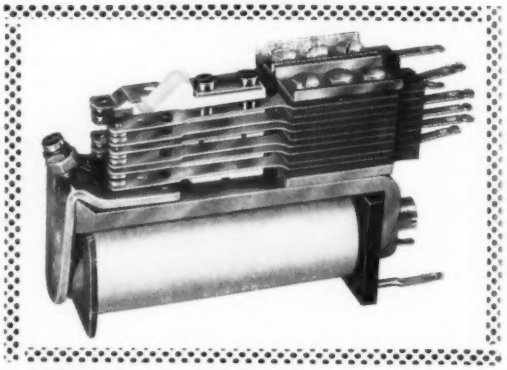

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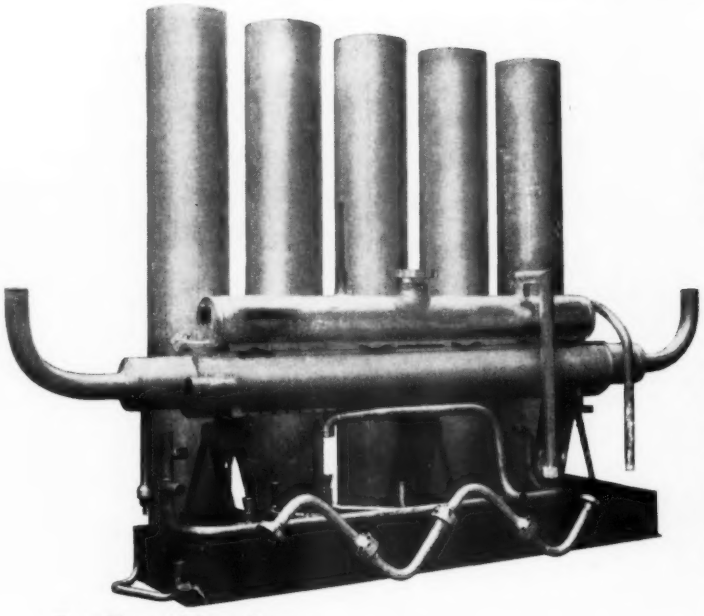

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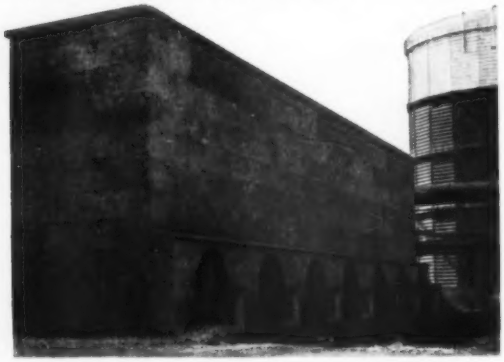

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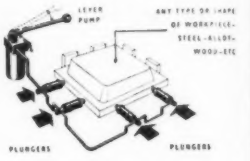

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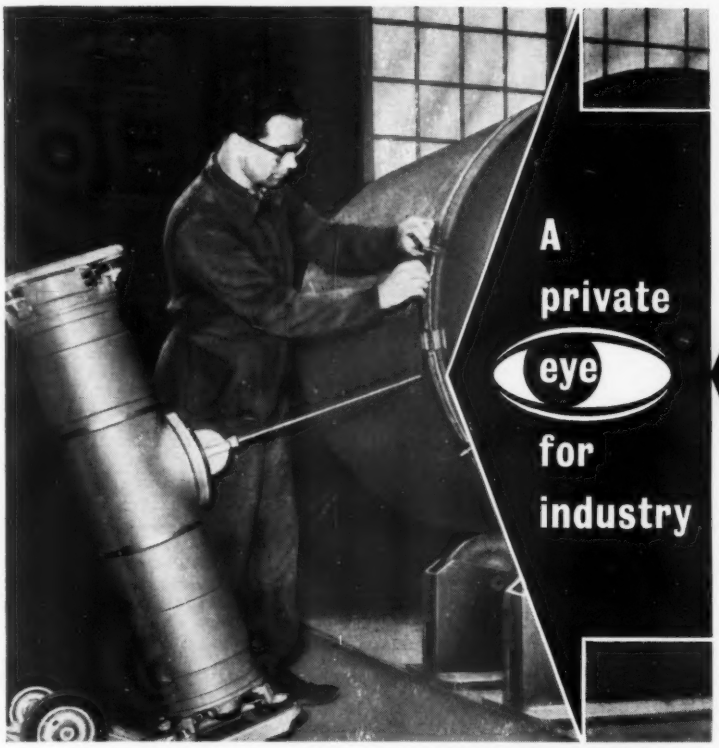

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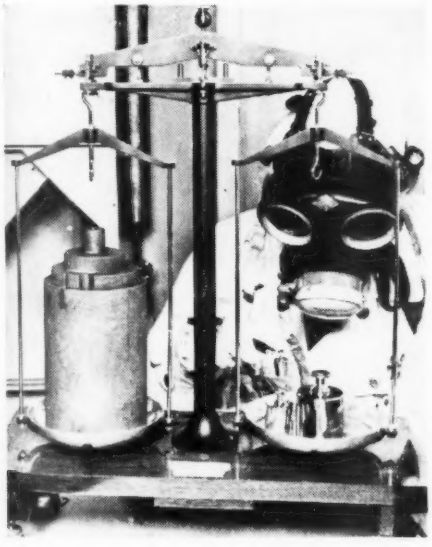

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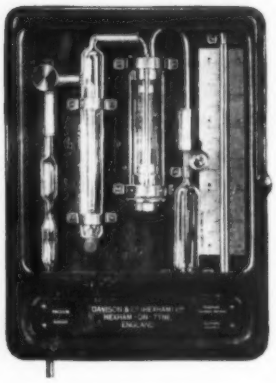

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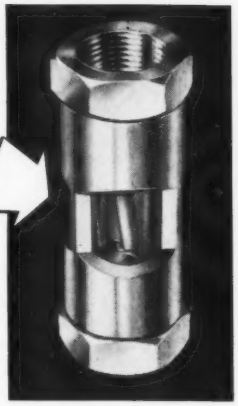

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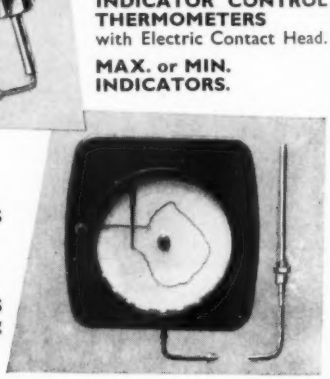

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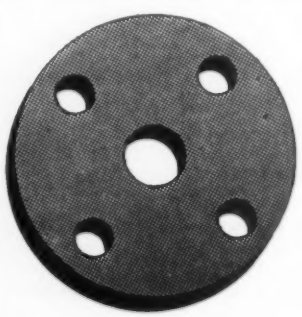

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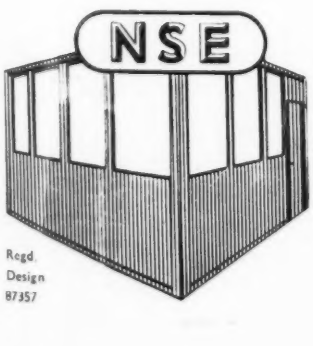

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